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THE EXAMINATION OF WATERS AND WATER SUPPLIES

(THRESH, BEALE & SUCKLING)

FIFTH EDITION

BY

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PREFACE

THE preparation of this edition, called for soon after the outbreak of war, has been carried out under conditions of extreme difficulty, and it has proved a much interrupted task. Its completion in 1941 was intended, but this hope was frustrated by the course of events which, amongst other things, resulted in the loss of much manuscript together with the material accumulated for its preparation. The book has, therefore, been out of print for nearly two years, and I apologise to all who have been inconvenienced by this delay. The frequent requests which have been made for the book and the sympathetic enquiries of many friends as to the progress of this edition have, however, been a much appreciated encouragement.

In the preface to the fourth edition, the death of Dr. J. C. Thresh, the first author of the book, was mentioned, and in this, I have to record the retirement of Dr. J. F. Beale, which took place in 1938 to the great regret of his many friends.

Since the date of the last edition, several outbreaks of water-borne disease, including typhoid fever, paratyphoid fever and acute gastro-enteritis, have occurred in this country, and served as timely reminders of the dangers to which water supplies are exposed. With increasing housing and industrial development and greater demand for water, the risks to many public water supplies become multiplied and no complacency is permissible.

Arising from the inspections of numerous waterworks situated in all parts of the country, I would emphasise the necessity for constant vigilance and increased precautions, together with greater resort to treatment processes and periodical revision of the circumstances. Such measures are necessary to maintain, and, in some instances, to improve existing conditions, and so secure safety in our public water supplies.

The majority of waterworks are well organised and efficiently administered. Of the minority, some of the older undertakings have been designed, arranged and extended with insufficient regard to the quality and treatment of the waters, and thus, the addition of treatment plant, when necessary or desirable, becomes very difficult or impracticable. Others, such as some of the smaller waterworks, have inadequate provisions and no expert management or technical control. It is sometimes apparent that the Medical Officer of Health and the Bacteriologist and Analyst have not been consulted in the location, design and control of the waterworks. In post-war planning, in which the development and improvement of waterworks should find a prominent part, the counsels of these officers should be more frequently obtained.

Owing to the inadequacy of underground supplies to meet the growing demand for water, greater resort to surface sources, such as

rivers, will be necessary in the future. The softening of hard waters meets the general desire of consumers and also avoids considerable national wastage of labour and materials. It is anticipated, therefore, that, as soon as circumstances permit, there will be considerable extension of water purification and softening installations.

In preparing this edition, particular attention has, therefore, been given to these matters. The text has been revised throughout and many chapters, including those dealing with pollution and water-borne diseases, the bacteriology of waters, purification and treatment processes, have been re-written and extended.

It is hoped that the book will prove of increasing use to Waterworks Authorities, Civil Engineers, Medical Officers of Health, Bacteriologists, Analysts, and all others interested in water supplies, and, by contributing to the prevention of water-borne diseases, it will benefit the Public Health.

I am grateful to many friends whose interest in the book has been shown by making suggestions or drawing attention to errors, and I ask indulgence for errors which will, I fear, appear in this edition owing to the pressure of other urgent work and the difficulties prevailing throughout its preparation.

I gratefully acknowledge the help rendered by my assistants, particularly Mr. C. W. Martin, F.I.C., Mr. G. D. Miles, B.Sc., Mr. W. C. Dewey and Dr. R. D. Gray, and I am greatly indebted to my secretary, Miss G. Butt, for the typing of manuscript and the reading of proofs. Finally, my best thanks are due to Messrs. J. & A. Churchill Ltd. for their patient and helpful attitude at all times.

E. V. SUCKLING.

LONDON.

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WATERS AND WATER SUPPLIES

PART I

CHAPTER I

REASONS FOR WHICH WATERS AND THEIR SOURCES ARE EXAMINED

UPON consulting the records of the examinations of waters and water supplies made during the past fifty years the reasons for which they were made are found to be very varied, and a study of these will serve as an introduction to the description of the methods employed in ascertaining the character of the waters and in the discovery of the causes of variation, and more especially of the sources of contamination. These records might be tabulated in many different ways, but probably it will be most useful if they are referred to somewhat in the order of their frequency.

1. The largest number of chemical and bacteriological examinations are those made periodically for Water Authorities to ascertain if the supplies maintain the required degree of purity and to discover the extent of any variations which occur.

2. Closely approaching these in number are the waters examined to ascertain the quality of the proposed supply to new houses in rural districts to enable the Sanitary Authorities to decide whether they are sufficiently good to justify them in issuing the necessary certificates permitting the houses to be occupied. As the samples submitted are generally from recently constructed wells, the water has suffered from soil disturbance and from contact with the wooden curb, the brickwork, etc., and this introduces factors which often make it exceedingly difficult to decide whether the water will ultimately prove suitable for domestic purposes or not.

3. When a Water Authority contemplates obtaining some additional source or sources of supply, extensive investigations have generally to be made, and numerous samples of water examined. It has to be proved that the water, when obtained, will be pure and wholesome, and not too hard for general domestic uses. Also, that the source is as free as possible from the risk of pollution or, if polluted or liable to pollution, the methods for treating the water can be absolutely relied upon to render it at all times pure and wholesome.

4. Numerous occasional samples are submitted to ascertain if they are suitable for domestic supplies or suitable for some particular purpose, such as brewing, paper making, tanning, photographic plate making, steam raising, wool washing, dyeing, etc.

5. The pollution of rivers often necessitates not only the examination of samples of the water taken at different parts and under different conditions, but also the examination of all tributaries, large or small, which may discharge crude sewage, sewage effluents, tarred road washings, trade waste, etc. With these are often associated investigations to ascertain the effect of the purification taking place during the flow down the stream, attributable to dilution and the various processes included under the name of self-purification.

6. Large numbers of sewage effluents are examined, often periodically, to ascertain if the sewage works are acting properly and producing effluents which are suitable for discharge into the adjacent streams. This often necessitates the examination of the river waters above as well as below the point of discharge.

7. River waters are examined to ascertain the effect of heavy rainfalls or of long-continued drought. Well waters have frequently to be examined for the same reason.

8. Well waters may have to be examined to ascertain the effect of pumping, more especially if situated near the sea or an estuary, when they may be susceptible to tidal influence.

9. Numerous samples are examined because they are alleged to fur boilers or hot-water pipes, or because they act upon pipes of iron, galvanised iron, or lead, or have some action on boilers or cause priming.

10. Where waters are submitted to a softening process they are examined to ascertain if the process is uniformly efficient.

11. During the construction of deep wells or boreholes, samples are examined from time to time to ascertain if the waters at different depths vary in character.

12. Where waters are submitted to various processes of purification, if at any time the water is not satisfactory, samples have to be examined at each stage to ascertain at what point the system is failing. This may entail a careful examination of the works from the source of supply to the point where the pumped water enters the mains. Often, also, water from different mains and water from the service reservoirs may have to be examined.

13. The analyses of waters used or proposed to be used for public swimming baths are frequently required in order to ascertain their suitability for such use, or to confirm the efficacy of the treatment processes.

14. The recent enactments fixing standards for different grades of milk and the general condition of dairies have caused many samples of water to be submitted for examination to ascertain if they are suitable for dairy purposes.

15. Not only are waters submitted when outbreaks of typhoid

fever have occurred, but frequently the water supply has been suspected where the outbreaks were of diphtheria, scarlet fever, etc. Not infrequently waters are examined to comply with the request that an opinion be given as to their suitability for use by persons suffering from rheumatism, gout, kidney disease, goitre, cancer, tuberculosis, etc., or, alternatively, if they are likely to cause such diseases.

16. Occasionally waters become infected by some particular organism, and its identification is desired with an opinion as to its origin, and how best it can be eliminated and infection prevented in the future. A water may have acquired a colour, taste, or odour, and the cause, etc., has to be investigated. The effect of the presence of certain low forms of vegetable life upon filter beds has also frequently to be considered.

17. Numerous samples are submitted for reports on the best method of purifying, of softening, or of preventing action on mains and supply pipes.

18. In some cases where water from the mains is said to be satisfactory, consumers may lodge complaints. In such cases the supply from the house taps has to be compared with that from the mains, and usually the water fittings in the houses have to be examined.

19. Occasionally water collected from the basement of buildings is submitted in order to ascertain whether this is a leakage from the mains, subsoil water, or sewage escaping from a drain.

The above do not include all the reasons for making examinations of water or of the sources of supply. Examinations have had to be made : (a) to ascertain the changes taking place when water has passed through condensers ; (b) to ascertain whether water from divers sources could be mixed ; (c) to ascertain to what extent, if any, water being pumped from coal mines and allowed to soak away into the chalk formation was affecting the waters in the wells around and to find in what direction it was travelling. From time to time other problems arise, and the more unusual they are the more interesting the investigation. With experience in all these matters it is not always possible to give a definite answer to a question which is frequently asked : if a well is sunk at such and such a place, what is likely to be the quality and the quantity of the water obtainable ?

In the following pages the question of quantity will be a very subordinate one, since it is almost entirely a question for the Water Engineer, and there should be no desire to trench upon his province ; but even an expert Water Engineer is sometimes glad to discuss such matters with a man who has had sufficient experience to justify him in expressing a guarded opinion. On the other hand, the Engineer will look to the Chemist and Bacteriologist for guidance in all questions of quality, and in the search for sources of contamination, or the causes of any change which may have been observed in the character of the water.

In the following pages an effort will be made to impart such information, based on an extended experience, as will enable the

majority of the problems likely to be presented to be successfully dealt with. Some knowledge of physics, chemistry, biology and bacteriology is assumed, and when the question is one affecting health some knowledge of medicine may be imperative.

The importance of the inspection of the source of supply, both in detecting possible sources of pollution and in enabling correct inferences to be drawn from the results of the chemical, bacteriological, and microscopical examinations, cannot be overestimated. This is now being recognised by sanitarians generally. In fact, Gruber, of Vienna, lays so great stress upon an examination of the source as to assert that in ordinary cases even a bacteriological examination of the water can be dispensed with, and Flugge considers that an inspection of the source and arrangements of the water supply, carried out with the unaided senses, is the most desirable method, and seldom needs to be supplemented by chemical, bacteriological, or microscopical investigations. Dr. Brown, reporting to the Massachusetts Board of Health (1890), stated: "To determine whether or not a water has been polluted by sewage, a chemical analysis is sometimes insufficient, sometimes it is superfluous. It does not need a chemical examination to decide whether a stream has been polluted by sewage when one can see the sewage flowing into it." And, again, "Standards are relics of days in which the harmfulness of a water was supposed to be the direct result of the injurious action of specific substances found in it. The theory of to-day is that it is (in the large majority of cases) to the presence of micro-organisms in water that its harmful influence is due, and that the results of chemical analysis have their highest value in the light that they throw on the quality of the water from the standpoint of bacterial contamination." "An opinion regarding the wholesomeness of a water must be based on all the information obtainable about it, such as location, environment, and source of the water, and the character and population of the drainage area."

Such an examination implies some knowledge of geology, as without this it is frequently impossible to locate the points at which impurities may gain access to the water, or to form an opinion as to whether a given source is adequately protected or not. There must be some knowledge of the nature and extent of the water-bearing stratum, and of the impermeable stratum below it, and also of that above it, if the supply is from a deep source. The locality and nature of any faults must also be studied, together with the angle of inclination of the strata and the direction of the fissures.

The geological maps of the Ordnance Survey are indispensable for this purpose. These maps are all on the scale of 1 inch to the mile. The "solid" maps show the distribution of the solid rock formations, the "drift" maps show the superficial deposits overlying them, the rock formation being coloured only where there is no drift. In parts of the east of England, where the superficial deposits are thick and widely spread, only the drift edition is published. From near Scarborough southward, over the east and south-east of England, the drift edition

Series of British Strata Commencing at the Surface

Post-tertiary

Alluvial deposits, blown sands, etc.

Glacial and post-glacial sands and gravels, boulder clay.

Tertiary

- Pliocene . . . The crags (sands and shells) of Norfolk, Suffolk, and Essex.
 Miocene . . . Almost unrepresented in Great Britain.
 Oligocene . . . Sands, clays, marls, etc., with limestone in their beds. Hampshire and Isle of Wight.
 Eocene . . . Upper Bagshot sand.
 Barton clay.
 Middle Bagshot beds.
 Bracklesham beds.
 Lower Bagshot beds. Clays and sands.
 London clay.
 Oldhaven, Woolwich, and Reading beds and Thanet sands.

Secondary or Mesozoic

- Upper Cretaceous . . . Upper chalk with flints.
 Lower chalk without flints.
 Chalk marl.
 Upper greensand.
 Gault.
 Lower Cretaceous . . . Lower greensand, Folkestone, Sandgate and Hythe beds, and Atherfield clay.
 Weald clay.
 Hastings beds, Tunbridge Wells sand, Wadhurst clay, Ashdown sands.
 Jurassic Upper or Portland oolites.
 Hard sandstones and limestone alternating with clay and shales. Purbeck beds. Portland stone and sand.
 Kimmeridge clay.
 Middle or Oxford oolite. Coral rag and calcareous grit.
 Oxford clay.
 Lower or Bath Oolite. Great oolite. Cornbrash, Forest marble, Bath or great oolite, Northampton sands.
 Fuller's earth.
 Inferior oolite. Lincolnshire limestone, Northampton sand.
 Lias Upper lias (shaly clay), middle lias (argillaceous limestone, sands and clays), lower lias (as middle lias).
 Triassic—
 Keuper Red marl. Contains beds of rock salt and gypsum.
 Keuper sandstone.
 Bunter Upper mottled sandstones.
 Pebble beds.
 Lower mottled sandstones.
 Permian—
 Upper Permian . . . Red sandstone, clays and gypsum.
 Magnesian limestone.
 Red and variegated sandstone.
 Lower Permian . . . Red sandstone, marl, breccia, and conglomerate.

Primary or Palæozoic

- Carboniferous . . . Coal measures. Sandstones, clays, coal, shales, flagstone and ironstone.
 Millstone grit.
 Sandstones with thin seams of shale, coal, and limestone.
 Carboniferous or mountain limestone.
 Yoredale rocks (limestone chiefly).
 Limestone and shales.
 Old Red Sandstone . . . Red sandstones, shales and conglomerates.
 Devonian Grey slate and limestone.
 Grey unfossiliferous slate.
 Soft slate with bands of limestone and sandstone.
 Silurian Ludlow rocks. Sandstone, limestone, shale.
 Wenlock limestone and shale.
 Llandovery shale and sandstone.
 Lower Silurian . . . Shales, slate, sandstone etc.
 Cambrian Slates, sandstones, etc.

Eozoic

Gneiss and crystalline schistose rock.

NOTE. The Permian and Triassic series are often included in one group as the "New Red Sandstone."

is the more useful for reference when considering the question of water supply, unless a supply from a deep source is contemplated, when the solid edition will be also required. For surface water supplies the ordinary maps, 6 inches or 25 inches to the mile, showing the contours and surface level at various points, are also required, as from these the catchment or drainage areas can be delineated. The handbooks supplied with each set of maps must also be consulted, and the knowledge thus obtained corroborated and extended by personal exploration of the locality.

The table on p. 5, which enumerates all the more important strata found in the British Isles, from above downwards, is one which frequently will be found useful for consultation, but it must be remembered that probably in no one locality do all these beds exist. Some are missing in one district, others in another; in certain districts some attain a considerable thickness, whilst in others they have so thinned out as to be unimportant. A few notes which may be of value are therefore appended regarding the more important formations, but they will frequently have to be supplemented by reference to text-books on Geology, particularly the "Memoirs of the Geological Survey" and "The Nation's Water Supply," by R. C. S. Walters, 1936.

CHAPTER II

GEOLOGY IN ITS RELATION TO SOURCES OF SUPPLY

As is well known, pure water does not occur in Nature. The purest is undoubtedly the rain which falls upon the oceans far from the neighbourhood of land. The rain droplets are probably all formed round a nucleus of foreign matter, and as these drops fall and coalesce the gases of the air and any matters suspended therein are taken up. Over the sea and over land near the sea, rain water always contains an appreciable quantity of common salt taken up from spray, and traces of salt are found in all rain waters however far the place of collection may be from the sea. Over large continents, as North America, isochlors can be mapped out showing how the chlorine (present as common salt, NaCl) decreases from the seaboard inland. These, however, cannot be traced in the British Isles, or certainly not with a precision which would render them serviceable. Having reached the ground surface, the rain water may merely run over the surface into the nearest brook, but in doing this it will take up some of the constituents of the rocks and soil with which it has been in contact. The amount will vary with the nature of the surface, duration of contact, distance from the coast, and other factors. It is usual to divide these surface waters into two groups: (1) Upland surface waters, and (2) Moorland waters, the former derived from the surfaces of bare rock and of uncultivated ground, the latter from more undulating surfaces, some of which may be under cultivation or used for pasturage of cattle.

Primary Rocks

Upland and many moorland waters are collected from the surface of the primary rocks.

The upland surfaces in Westmorland, Cumberland, West Somerset, Devon and Cornwall consist chiefly of Devonian slates and limestone, whilst the Silurian and Cambrian rocks form the surface in Wales and the Lake District, and the Eozoic rocks at Malvern, Charnwood Forest, Anglesey and the adjacent parts of Caernarvonshire. Of the igneous rocks, granite is the only one which occurs over any extended area. In the south-east of Ireland there is a mass of granite seventy miles in length and from seven to seventeen miles in width. Large intrusive blocks of granite occur in the south of Scotland and in Devon and Cornwall.

From these rocky surfaces, the water runs off rapidly, and, filling hollows in the mountains, may form lakes, many of which are now being utilised for the supplies of cities long distances away.

The following is an example of this kind of water. It is from Loch Katrine :

*Electric conductivity at 20° C.	50
pH	6.5
Free carbonic acid	0.25 per 100,000
Calcium carbonate	0.35 "
Calcium sulphate	0.25 "
Magnesium sulphate	1.15 "
Sodium chloride	0.8 "
Organic matter with traces of silica	0.75 "
Total solids	3.3

These upland waters rarely contain any free acid except carbonic (CO_2), but occasionally there may be a trace of some free organic acid derived from peat or the rootlets of heather, or bilberry, or from bog moss. In the next group of waters free acid is more often met with.

The **Metamorphic rocks** (quartz, mica, schist, gneiss, granite, and crystalline limestone) are almost absolutely impervious, as also are the slates of other series. The sandstones are slightly pervious. The limestones of the Silurian and Devonian systems are so hard and compact that they yield very little calcium carbonate to the rain falling upon them.

The waters from hilly undulating districts, grass and moorland, are usually found to contain more saline matter in solution than upland surface waters. Whilst much of the rainfall runs rapidly over the surface and forms streams, a good deal is absorbed by the thin layer of soil, takes up soluble matter, and gradually oozes away into the rivulets. Where bogs abound, organic matter becomes dissolved, containing salts of organic acids, one of which is quinic acid found in bog moss and in rootlets of bilberry and heather; another is humic acid, derived from peat, and occasionally there may be some other free acid besides carbonic. In the neighbourhood of towns, as, for example, on the moors between Wakefield and Sheffield, where lime is burned and coal consumed in large quantities, the sulphuric acid formed by oxidation of the sulphurous acid in the smoke may be more than sufficient to liberate all the organic acid in the moorland water, and a trace of free sulphuric acid be present. The degree of acidity, however, is very variable.

Where reservoirs have been constructed to store the waters—and such reservoirs abound in Yorkshire and Lancashire—a certain equalisation takes place, but the water may still be acid and vary considerably from time to time.

Calcareous and non-calcareous rocks may be exposed in the same watershed, and to some extent the nature of the water collected will depend upon the relative areas. The limestone of these formations is so hard that water dissolves very little, but it may be sufficient to neutralise the acid derived from vegetation. During an inspection the

* Vide Chapter XVI.

reaction of the water can be ascertained by adding a little brom-thymol-blue solution. An acid water will give a yellow colour, a neutral water a green tint, and an alkaline water a blue colour.

Acid waters from the moorlands in the north of England were responsible for the numerous cases of lead poisoning which used to occur (and still occur in certain localities) before methods were adopted for neutralising the free acid and introducing a little calcium carbonate into the water.

Certain formations included in the primary series of rocks may be referred to in a little more detail since many of them not only yield surface water, but also absorb water which may reappear in springs or wells.

The Old Red Sandstone. According to Woodward the formation "comprises great series of red sandstones, quartzite conglomerates and red and mottled marls with beds of calcareous sandstones or concretionary limestone known as 'cornstones.' The ground is of varying character, mountainous in parts of Carmarthenshire and Brecknockshire, elsewhere on the Welsh and English borders a land of pasture and orchards." Moorlands characterise this formation in the Cheviots. The formation extends from near Bridgnorth in Shropshire, southward through a considerable portion of the counties of Hereford, Monmouth and Brecon into Glamorgan, Carmarthen and Pembroke. As a rule, water obtained therefrom contains very little soluble matter, and is usually moderately soft and well adapted for domestic purposes. It is obvious that in a formation which in one place may be limestone and in another sandstone, waters of very varied character may be found in the fissures and body of the rocks. As a water-bearing formation it is comparatively unimportant, especially compared with the red sandstones of the Secondary rocks.

The formations above the Old Red Sandstone become more important on account of water other than surface water being obtained therefrom.

The Carboniferous Limestone. This stretches from Northumberland through north Yorkshire to Lancashire and mid-Derbyshire, forming the axis of the Pennine Chain. The stratum is much fissured, and springs occur of all volumes from a mere trickle to a decided river. The River Aire arises from such fissures near Malham. Usually the water is very clear and palatable, but it is often too hard for domestic purposes. It is notoriously liable to contamination on account of the size of the fissures and the numerous swallow-holes. Surface water from this formation is often discoloured by peat and may contain traces of iron.

The Yoredale Rocks and Millstone Grit. These non-calcareous rocks occur in South Wales, Derbyshire, Yorkshire, Lancashire, and North Staffordshire, and are but slightly pervious. A considerable portion of this area is very hilly and a large quantity of water is collected therefrom to supply many of the manufacturing towns of Lancashire and Yorkshire. As sources of water supply, other than from the

surface, they are comparatively unimportant, being too dense and impermeable. Springs arise from fissures, and in a few places water is derived from deep borings. The water from such springs and borings varies much in character, but is usually moderately soft.

The Coal Measures. This formation consists of shales and sandstones, with seams of coal and bands of ironstone (Woodward). They are of little importance as sources of water supply, although immense volumes are pumped to waste from coal mines. The waters in such mines are often quite suitable for domestic use, but the risk of pollution is very considerable. On occasions they contain large quantities of salt, and the water pumped to waste at Tilmanstone, Kent, is soft and contains sodium carbonate. Some millions of gallons are pumped to waste daily from this pit, yet it would make a good and wholesome supply for domestic purposes. The coal measures at the Shakespeare pit of the Kent Coal Company yield a water which contains large quantities of sodium chloride. An excellent account of these waters was given by Mr. Foster Brown in a paper contributed to the Institution of Civil Engineers, Session 1922-1923, and entitled, "Underground Waters in the Kent Coalfield and their Incidence in Mining Development."

The Secondary Rocks

"These stretch across England from the mouth of the Tees to the mouth of the Exe, with a branch running to the mouth of the Mersey" (Woodward). The lias, new red sandstone, conglomerate sandstone, and magnesian limestone formations yield from their moorland surfaces a water closely resembling that from the mountain limestone. All absorb water more or less freely, and this can be recovered from springs and wells.

Permian. Red Sandstone and Conglomerate. These "form picturesque hilly ground with deep coombes near Torquay, Teignmouth, and Dawlish, in Devonshire. The sandstone also occurs in Yorkshire, west of Doncaster, in Cumberland and Durham, and at Penrith, Wolverhampton, south of Shrewsbury, and across the Dudley coalfields." The water obtained from this formation resembles that from the New Red Sandstone above the Magnesian Limestone.

The Magnesian Limestone or Dolomite. This compact stratum has a thickness of 300 feet at Durham, and this thickness is maintained southwards to Pontefract, but it thins out further south towards North Wales. The water yielded by wells and springs is not very abundant, and is usually very hard, the "permanent" hardness often being considerable.

The New Red Sandstone of the Trias. These rocks "form part of the plain of York and stretch through Nottinghamshire, Lincolnshire, Derbyshire, Cheshire, South and East Lancashire, Staffordshire, Warwickshire, Worcestershire and Gloucestershire, and there is an outlying mass near Carlisle" (Woodward). The Keuper marls contain veins of gypsum and beds of rock salt, hence water from these portions

of the formation may contain much calcium sulphate or sodium chloride. The sandstone strata are of very great importance as sources of water supply, the rock being very pervious and absorbent. They rank next to the chalk in abundance of yield. An immense number of shallow wells are sunk therein and many towns are supplied from deeper wells and from springs in this formation. The sand granules, of which the rocks are composed, are cemented together by calcium sulphate and carbonate, hence the water is usually very hard, though much of the hardness is removable by boiling. In some localities magnesium sulphate is found in the water, in others an excess of sodium chloride. The unpolluted waters from this formation are usually clear, bright, colourless, palatable and wholesome, but many are too hard for cleansing, steam raising, and various manufacturing purposes. The variations in character within a limited area are sometimes quite considerable. In sinking a well near Warrington, waters entered at three different depths and all varied greatly in character. One was so hard as to impair the usefulness of the mixed well water for domestic purposes. When this was located and excluded a water of unusual excellence was obtained.

The Lias. This is an unimportant water-bearing formation consisting of clays, limestone, and shales, with local beds of ironstone. It extends across England from Whitby on the coast of Yorkshire to Lyme Regis on the coast of Dorset. In a few localities it yields a fair amount of water and springs of large volume are not infrequent. The water usually contains much calcium carbonate, and at times the amount of sodium chloride may be excessive.

The Oolites. The Upper and Middle Oolites (granular limestone) are of little importance as sources of water, but the Lower Oolite, which is separated from the Middle Oolite by the Oxford Clay and has a thickness ranging from 300 to 600 feet, is a prolific source of underground water. "The inferior oolite series, comprising sands with overlying limestone, extends from Burton, Bradstock and Bridport, to Yeovil, Bath, Dundry and the Cotswold Hills. The great oolite, which rests upon the inferior oolite, occurs in Lincolnshire, Northamptonshire, Gloucestershire and Oxfordshire, and is from 250 to 300 feet in thickness. Within the Thames Basin it has an area of 300 square miles and gives rise to numerous springs, the water being usually thrown out by the outcrop of fuller's earth. Below the fuller's earth is a series of beds, the most important of which is the Lincolnshire oolite, which in that county attains a thickness of 200 feet. This inferior oolite and the underlying sands are about 320 feet thick near Cheltenham and thin off to disappear under Oxfordshire." It follows, therefore, that a large quantity of water is held in these strata and can be reached by wells, whilst the overflow escapes from springs, some of which at the base of hills are of considerable volume. The water naturally contains much calcium carbonate, and in all respects resembles typical chalk water, save where it is imprisoned or flows very slowly through some zeolitic stratum, when it undergoes a change in character, a portion of

the calcium being removed and sodium substituted. The water is then alkaline like the deep well waters in Essex and London.

This oolite, where accessible, rivals the Chalk as a source of water, both in quality and quantity, but the extent is comparatively limited. Being more compact than chalk the water can only accumulate in and travel through fissures, hence polluting matters gaining access to such fissures may be carried long distances.

The Wealden. This comprises the pervious Hastings Beds of sands and sandstone overlaid in parts by the impervious Weald Clay. "They form the elevated tract in the Weald at Tunbridge Wells, Crowborough and Ashdown Forest, Mayfield and Heathfield, and the cliffs near Hastings" (Woodward), and are found in Surrey, Sussex, Kent, Dorset, and the Isle of Wight. The total thickness of the Wealden series is said to be 1,500 feet. The Hastings Beds consist of sands with intercalated beds of clay which receive different names according to the locality in which they are most developed. In order, from above downwards, the two chief divisions are the Tunbridge Wells Sands and the Ashdown Sands separated by the Wadhurst Clay. The Tunbridge Wells Sands have a thickness of about 180 feet at the town of that name but elsewhere they may have a much greater depth. The Ashdown Sands are said to be in parts 500 feet thick, and yield more water than the Tunbridge Wells Sands. At the last-mentioned place the water supply is derived from wells which pierce the Wadhurst Clay, hence it is derived from the Ashdown Sands. All these sands are very ferruginous, and generally the water derived therefrom contains so much iron in solution (as ferrous carbonate) that it becomes turbid on exposure to air and requires special treatment to render it usable; in addition, the water often contains appreciable traces of manganese. The water is usually soft, and sometimes the calcium salts have been partially replaced by sodium salts, when it acquires a faintly alkaline reaction.

The Lower Greensand, the lowest stratum of the cretaceous formation, lies between two impervious strata, the Gault above and the Weald Clay below. The outcrop extends from Folkestone, in a band of varying width, westward through Ashford, Maidstone and Reigate to Farnham. It then bends southward to Petersfield and finally eastward to the coast at Eastbourne. The southern half of the Isle of Wight is in great part formed of the Lower Greensand. There is a limited outcrop at Leighton Buzzard. The area of this formation in the London Basin is about 500 square miles and its thickness is from 200 to 500 feet. At Reigate the sands attain a thickness of 450 feet; in Bedfordshire, 250 feet. In both cases the dip is towards London, but apparently the stratum is absent under the metropolis, as borings have failed to discover it. The beds are also found in Cambridgeshire, and in Norfolk at Sandringham and Hunstanton. Beds believed to belong to the same formation are also found in Lincolnshire and Yorkshire. It is, however, to the south of London that the sand is important as a source of water. Though springs are not numerous from this formation there are some copious ones near Sevenoaks,

Dorking, Weston Street and Farnham, the water being thrown out at the outcrop of the Weald Clay. Usually the water contains little calcareous matter or saline matter of any kind, is very bright, free from colour, and pure, but it occasionally contains ferrous carbonate, especially in the neighbourhood of Folkestone, where the sand receives the name of the Folkestone Beds.

The Upper Greensand. This formation lies upon the Gault and is covered by the Chalk, no impervious bed of clay intervening, and in outlying areas, Norfolk, Lincolnshire and Yorkshire, the overlying chalk is of a red colour. The formation is but little developed under London, but it becomes of importance as a water-bearing stratum to the south and west. In parts of Dorset it is 100 feet thick, and fringing the Wealden district it has an average thickness of about 60 feet. "At Petersfield it is 80 feet, at Eastbourne 40 feet, at Godalming 50 feet and at Nutfield 40 feet. It is exposed north of Folkestone and at East Wear Bay with a thickness of less than 20 feet. It is essentially a water-bearing stratum" (Woodward). The water varies very much in character. Where it is overlaid by the Chalk it closely resembles water from that formation, but where exposed it may contain little calcareous or other saline matter, and in certain localities it is decidedly ferruginous.

Chalk and the Lower London Tertiaries. These are considered together, since where the Lower London Tertiaries overlie the Chalk the water in the latter is often very markedly affected by having passed through the beds above.

The beds in order from above downward include:—

The London Clay. Almost impervious.

The Oldhaven and Blackheath Beds. Shelly sands with clay.

The Woolwich and Reading Beds. Mottled sands and clay with pebbles.

The Thanet Beds. Coloured sands admixed with varying proportions of clay. Rich in zeolitic sands.

All the sands may yield a little water, especially those of the Thanet Beds, but some of the water percolates downwards into the Chalk upon which these beds rest. All these sandy beds have a limited outcrop round the edge of the London Clay, chiefly at the places from which they derive their names.

The Chalk formation is the important one as regards the supply of water, more especially where the Chalk is at, or near, the ground surface. Where the Chalk is covered by sands and clay, the latter have been crushed or washed into the fissures and greatly reduce the water-holding capacity of the chalk, since nearly all the available water in this formation is obtained from the fissures. In fact, these fissures may be so completely blocked that adits in the Chalk below its line of saturation may be driven for miles without yielding enough water to supply a small community, as at Richmond, Surrey.

According to Woodward, "The Chalk extends from Flamborough Head inland, forming the Yorkshire wolds, and thence running beneath the Humber near Hull to form the Lincolnshire wolds. It constitutes

the foundation of the greater part of Norfolk and Suffolk, but is in these counties very much concealed by glacial drifts, and does not there appear in such conspicuous hills as those which extend from Royston and Luton Downs to the Chiltern Hills, the Marlborough Downs and Salisbury Plain. Thence the Chalk stretches out irregularly to the west beyond Dorchester, and is found in outliers near Chard, Seaton and Sidmouth. Eastward of Salisbury Plain the Chalk forms a large extent of Hampshire, it is found in the Isle of Wight and borders the Wealden district, forming the cliffs from Margate to Folkestone on the north and those from Beachy Head to Brighton and Littlehampton on the south. It is also exposed at Gravesend and Grays Thurrock." It is bare over more than half of Hertfordshire, but to the south-east and in Middlesex it is covered with London Clay. It extends under the whole of Essex and London, but is covered with London Clay and more recent deposits. In the London Basin it extends over an area of upwards of 2,000 square miles, and has a thickness in places amounting to 1,000 feet. Its enormous area, so much of which is exposed, and its fissured character render it the most important water-bearing stratum in the south-east of England, and probably in all England. The fissures are often so large that they become "bournes," or swallow-holes, a bourn being a fissure through which water issues freely when the water level in the chalk is above that of the orifice of the fissure. When the plane of saturation is below that of the fissure, water from the surface may flow into it, and it becomes a swallow-hole. It is the abundance of these fissures which makes it so difficult to protect the water from chalk wells from contamination. When large quantities of water are required adits are driven from the sides of the well below the level of saturation in order to cut as many of these fissures as possible. Springs are numerous and often yield very large volumes of water, but along the outcrop of the Gault they are not so large as those derived from the Chalk where it has passed under the London Clay and again become exposed at or near the sea level.

Water from the Chalk not affected by having passed through any superincumbent strata is especially characterised by its palatability, brilliancy and freedom from colour. The chief saline constituent is calcium carbonate held in solution by carbonic acid, and so much may be present that the water is too hard for domestic use, steam raising and many manufacturing purposes; hence it has frequently to be submitted to some softening process. Pure chalk water only needs treatment with lime to remove the carbonic acid, but water which has passed through superficial beds before reaching the Chalk may contain calcium and magnesium sulphate and chloride, necessitating more complicated systems of softening. Of special interest is the water which has passed through the Thanet Sands. In its transit the calcium and magnesium become replaced by sodium, and the character of the water is entirely changed. This subject will be referred to later.

The London Clay, being practically impervious, yields little or no water, but in certain areas where it has become loamy (chiefly by

intercalation of laminae of calcium sulphate) a little water can be obtained, though it is usually too sulphated to be usable for domestic purposes, and occasionally contains so much sulphate as to form a mineral water with decided medicinal properties. At the base of the London Clay the sands yield a little water, but this is usually sulphated like that derived from near the surface. If this water is cut out and the boring extended into the Thanet Sand, water is more freely obtained and is of an entirely different character. Where the superficial clays and sands are hundreds of feet thick, the boring may be continued into the Chalk without the slightest increase in the yield of water, the Chalk having become practically impervious.

Round the coast and up the estuaries, tidal water gains access to the Chalk, and its effect can be traced for many miles inland. The water in the Chalk under London is being derived in varying proportions from all around, and it therefore varies in character according to the strata through which it passed before reaching the chalk. To the east and north-east where tidal water is gaining direct access (at Barking and the coast around Harwich), it is affected by this admixture. The various analyses given later in tabulated form show how varied is the character of the water derived from the Chalk. The tables also include what may be called typical chalk waters from many different counties.

Barton, Bracklesham, and Bagshot Beds. These consist chiefly of sands and are very local, their names indicating the localities where they occur. The Bagshot Sands are the most important and are found in the Isle of Wight and capping many hills near London. They form the Frimley and Chobham Ridges, the Heath of Bagshot, Hartford Bridge and Sandhurst. They usually yield a soft water which may be ferruginous. Many patches yield water containing little or no calcium carbonate and acting markedly on lead, zinc and iron. Cases of lead poisoning are occasionally reported from such localities. Round the edges of patches of these sands resting on hill tops, the water oozes away, and springs are numerous but small. In the London Basin the formation varies from 100 to 350 feet in thickness, and extends over an area aggregating more than 200 square miles.

The Crag of East Anglia. These are shelly sands and gravel of limited area and yielding very little water. Springs are rare, as the area covered is comparatively flat. Extending to the coast the sands are often impregnated with sea water, and occasionally they are very ferruginous.

Post-tertiary

Recent Deposits. Alluvial and Glacial Drifts. The formations so far considered have "regular outcrops and are disposed in fairly regular sequence: the older for the most part in the north of Great Britain, and the newer in the midland, south-eastern and eastern regions" (Woodward). The general dip is towards the south and east. During

the Glacial periods the immense glaciers moving southward sheared off masses of rocks which they crushed and ground as they carried them forward. Ultimately the *débris* was deposited on the land the glaciers had covered when the ice receded. Hence in these areas are found boulders, gravel and sand of various ages, and also beds of clay, the latter, when containing an admixture of stone, being called "boulder clay." The drift maps of the Geological Survey must be consulted to ascertain the distribution of these deposits. They are more widely distributed than any older stratum, and vary in thickness from a few inches to 150 or even 200 feet. In some districts the whole deposit may be of the nature of boulder clay, and the boulders embedded in the clay are in some cases chalk, in others limestone, in others sandstone, etc. In other areas the deposit may be all sand or all gravel, or more usually sandy gravel. Probably the majority of shallow wells are sunk in these sands and gravels, otherwise the drift would have little interest regarded as a source of water supply. It is, however, important as bearing upon the character of deeper-seated water since the soluble salts in the drift vary in different localities. These are taken up by the water passing through on its way to some older formation, as of chalk, sandstone, etc., and the waters from these older formations are correspondingly affected. These recent deposits, moreover, include nearly all our cultivated land, hence the water they absorb is markedly affected by manures. Moreover, as such fertile areas yield water at a very slight depth, they were the portions first selected for settled populations, and in many districts the limited portion of sand and gravel became the nucleus of the existing villages and hamlets.

No boulder clay seems to be quite impervious, and sufficient water may be obtained from one well to supply a cottage or even a farm, but generally the water is very hard, and occasionally it may have an odour of sulphuretted hydrogen. This gas is not uncommon in water from alluvium containing organic matter, and in which particles of iron pyrites are embedded.

It is obvious that there can be no such thing as a typical well water from these deposits, but usually on a given gravel patch some portion yields unpolluted water and is fairly uniform in character, and samples of these may be taken as standards with which to compare water obtained from other portions. As many hills are capped with drift, springs are very common, but they are rarely of any magnitude.

Analyses of water from those various sources are given in a later chapter.

The L.G.B. report on "Water Undertakings," 1914, gives the following summary of the quantities of water derived from different geological formations in England and Wales :—

The total amount of underground water supplied by piped services for domestic purposes may be put down very roughly as 285,000,000 gallons a day. This does not include supplies from surface springs, nor water obtained from standpipes.

The following table shows roughly the amount derived from each geological formation :—

	Million gallons daily
Chalk (including over 40 millions taken by Metropolitan Water Board)	139 $\frac{3}{4}$
Bunter	71 $\frac{1}{2}$
Magnesian Limestone	13 $\frac{1}{4}$
Superficial Deposits (shingle, alluvium, river, valley and plateau gravels, and glacial sands and gravels)	13
Sandstones from Coal Measures	7
Millstone Grit	6 $\frac{1}{4}$
Lower Greensand (Folkestone and Hythe beds)	5 $\frac{1}{2}$
Keuper Sandstones	4 $\frac{3}{4}$
Lower London Tertiaries (Woolwich and Reading beds, and Thanet sands)	3 $\frac{1}{4}$
Carboniferous Limestone	3
Ashdown Sand	2 $\frac{3}{4}$
Lincolnshire Limestone	2
Corallian Beds	2
Great Oolite	2
Upper Greensand	1 $\frac{3}{4}$
Lias	1 $\frac{1}{4}$
Old Red Sandstone	1
Other formations yielding less than one million apiece	5 $\frac{1}{4}$
	<hr/> 285 <hr/>

Underground Supplies furnished by each County. The following table from the same Report shows the approximate amount of water derived from underground sources in each county, and the principal formations from which it is obtained :—

	Million gallons daily
KENT.—Including 28 millions from chalk (of which 17 millions are taken by Metropolitan Water Board) and 2 millions from greensand	32
STAFFORDSHIRE.—Including 26 $\frac{1}{2}$ millions from Bunter and 1 million from Keuper	29
YORKSHIRE.—Including 13 $\frac{1}{2}$ millions from chalk, 2 millions from Bunter, and 1 $\frac{3}{4}$ millions from corallian beds, and 1 $\frac{1}{2}$ millions from coal measures	20 $\frac{1}{4}$
HERTFORDSHIRE.—Almost entirely derived from chalk (over 7 millions of which are taken by Metropolitan Water Board)	19
LANCASHIRE.—Nearly 16 millions from Bunter, and over a million apiece from coal measures and millstone grit	18 $\frac{1}{4}$
SUSSEX.—Including 11 millions from chalk, 2 millions from Ashdown sand, and $\frac{3}{4}$ million from Tunbridge Wells sand	14 $\frac{1}{2}$
ESSEX.—Including 11 $\frac{1}{2}$ millions from chalk (of which 4 $\frac{1}{2}$ millions are taken by Metropolitan Water Board) and 2 $\frac{1}{4}$ millions from Lower London Tertiaries	14 $\frac{1}{4}$
SURREY.—Including 11 $\frac{3}{4}$ millions from chalk, and 1 $\frac{1}{4}$ millions from lower greensand	13 $\frac{3}{4}$
DURHAM.—Including 12 $\frac{3}{4}$ millions from magnesian limestone	13 $\frac{1}{4}$
NOTTINGHAMSHIRE.—Including 12 $\frac{1}{2}$ millions from Bunter	13
THRESH'S WATERS.	2

	Million gallons daily.	
HAMPSHIRE.—Including nearly 11 millions from chalk	12	
MIDDLESEX.—Almost entirely obtained by Metropolitan Water Board, and is apportioned between chalk (over 6½ millions) and gravel beds fringing the Thames (over 4½ millions)	11½	
CHEESHIRE.—Including 9 millions from Bunter, and ¾ million from Keuper	10¼	
LINCOLNSHIRE.—Including 4½ millions from chalk, and 1½ millions from Lincolnshire limestone	6½	
DERBYSHIRE.—Including 2¾ millions from alluvial deposits lining the Valley of the Derwent, and 2¼ millions from millstone grit	5½	
COUNTY OF LONDON.—The Metropolitan Water Board derive supplies from chalk exceeding 5½ millions	5½	
DORSETSHIRE.—Including 3 millions from chalk and 1 million from gravel beds in the valley of the Stour	5½	
SOMERSETSHIRE.—Including 2 millions from Keuper and 1½ millions from carboniferous limestone	4½	
BERKSHIRE.—Including 3 millions from chalk	3½	
BEDFORDSHIRE.—Including 1½ millions from chalk and 1 million from great oolite	3¼	
WARWICKSHIRE.—Including 2 millions from sandstones of coal measures	3¼	
SUFFOLK.—Including 3 millions from chalk, and the remainder from Crag	3¼	
WILTSHIRE.—Including 2½ millions from chalk	3	
WORCESTERSHIRE.—Wholly represented by Bunter	2¾	
BUCKINGHAMSHIRE.—Including 1½ millions from chalk	2¾	
GLOUCESTERSHIRE.—Derived mainly from millstone grit, Bunter, Old Red Sandstone, and inferior oolite	2¼	
NORTHAMPTONSHIRE.—Mainly derived from marlstone (Middle Lias), Lincolnshire limestone, Northampton beds, and river gravels	2¼	
NORFOLK.—Obtains over a million from chalk and the remainder from lower greensand	1½	
CAMBRIDGESHIRE.—Derives 1 million from chalk and the rest from lower greensand	1¼	
OXFORDSHIRE.—Obtains the bulk of its supply from gravel beds bordering the Thames, and from chalk	1	
CORNWALL.—From granite and palæozoic strata, including water from mine sinkings	1	
GLAMORGANSHIRE	Small underground supplies from ½ million to 1 million each	4½
SHEROPSHIRE		
DEVONSHIRE		
NORTHUMBERLAND		
LEICESTERSHIRE		
MONMOUTHSHIRE		
HEREFORDSHIRE	Less than ½ million each	1½
DENBIGHSHIRE		
HUNTINGDONSHIRE		
FLINTSHIRE		
RUTLANDSHIRE		
PEMBROKESHIRE		
MERIONETHSHIRE		
CUMBERLAND		

Million gallons
daily.

ANGLESEY . . .	} No underground supplies.	
BRECKNOCKSHIRE . . .		
CARDIGANSHIRE . . .		
CARMARTHENSHIRE . . .		
CAERNARVONSHIRE . . .		
MONTGOMERYSHIRE . . .		
RADNORSHIRE . . .		
WESTMORLAND . . .		
Total		285

It must be remembered that the information applies only up to the year 1914, though the changes since may not have been great. Where water is required in large quantities it is often cheaper to acquire upland or moorland sources, or to impound and purify water from local rivers. Such supplies are not included in these returns.

According to the *British Waterworks Directory*, 1936 edition, p. xii :

"The latest statistics available of the Water Undertakings in England and Wales were given by Sir Gwilym Gibbon, C.B., C.B.E., when Director of the Local Government Division of the Ministry of Health, in evidence before the Parliamentary Joint Committee on Water Resources and Supplies on the 11th July, 1935 :—

" 'In England and Wales there were 530 local authorities and 15 joint boards supplying water under the Public Health Acts ; 260 local authorities and 33 joint boards supplying water under powers given by special Acts ; 173 companies acting under statutory powers, and about 80 companies without statutory powers. In addition, there were about 1,000 private proprietors supplying small areas. There were thus 1,011 bodies supplying water under general or special statutory powers, and some 1,080 companies and persons undertaking supply without statutory powers.' "

"Another computation was given in the 'Local Government Supplement' to *The Times* of 10th December, 1935 :—

" 'In England and Wales to-day some 95 per cent. of the population with a piped supply is supplied by the 293 local authorities and 173 companies acting under special Acts. The Metropolitan Water Board directly supplies nearly 20 per cent. of the population of England and Wales, and very populous areas are covered by the other large corporations ; so that some 85 municipal and private undertakings supply directly 75 per cent. of the population. There are also 30 companies supplying populations from 50,000 to 500,000 and at least 200 other authorities, municipal and private, supplying populations between 10,000 and 50,000, leaving about 1,750 smaller authorities scattered all over the country to supply the remainder of the people, estimated at less than 5,000,000.' "

CHAPTER III

THE CHARACTER OF WATER FROM DIFFERENT GEOLOGICAL SOURCES

THE salts found in potable waters are very few in number, and whilst some of them are found in practically all natural waters, others occur in comparatively few, yet it is upon their quality and quantity that the character of the water depends.

Calcium, magnesium and sodium salts are found in nearly all waters, in the form of carbonates, sulphates, chlorides, or silicates. In order of frequency they may possibly be arranged as under :—

1. Sodium Chloride.
2. Calcium Carbonate.
3. Magnesium Carbonate.
4. Calcium Sulphate.
5. Magnesium Sulphate.

Salts which are less frequently found are :—

6. Sodium Nitrate.
7. Calcium Chloride.
8. Calcium Nitrate.
9. Magnesium Nitrate.
10. Magnesium Chloride.
11. Sodium Sulphate.
12. Sodium Carbonate.
13. Iron, usually as Ferrous Carbonate, sometimes as Ferric Sulphate.

Small amounts of silicates occur in all waters.

Usually with the sodium salts a trace of potassium is found, though rarely in sufficient amount for accurate estimation.

Practically all waters contain gases taken up from the air, and generally free carbonic acid taken up from the air and soil. A little organic matter is invariably present ; in pure waters, in actual solution, in less pure waters, generally in a colloidal condition. This, however, is being left out of consideration for the present. All these natural waters can be included in the following three groups :—

1. Acid waters with a hydrogen ion concentration represented by pH 4.5 or under. These contain some free acid other than carbonic. This includes the acid moorland waters, and very few others.

2. Alkaline waters having pH value of 8.5 or over. These all contain sodium carbonate, and little or no free carbonic acid. They are not numerous, but occur more frequently than is generally supposed.

3. Neutral waters with pH value between 8 and 6. This includes

the great majority of potable waters. These may be divided into three sub-groups according to the amount of saline matter held in solution, or, what is practically the same thing but much more easily determined, according to their electric conductivity (see p. 198).

Sub-group A would include all waters containing little mineral matter in solution and having an electric conductivity under 200.

Sub-group B would include all waters containing only a moderate amount of saline matter in solution, and with E.C. ranging from 200 to 1,000.

Sub-group C would include waters containing an unusual amount of saline matter and with E.C. over 1,000.

Waters belonging to sub-Group A will all be soft; those of sub-Groups B and C may be soft or hard. The importance of ascertaining as early as possible to which group and sub-group a water belongs will become evident when the actual analysis of a water is being undertaken.

Waters are usually classed as "hard" or "soft" according to their action on soap. The less the amount of soap required to produce a lather the softer the water. As there is no sharp line of demarcation between a "soft" and a "hard" water, adjectives such as slight, moderate, excessive, etc., are of use.

A water with under 5 parts per 100,000 of hardness may be said to be soft.

A water with 5 to 10 parts per 100,000 of hardness may be said to be moderately soft.

A water with 10 to 15 parts per 100,000 of hardness may be said to be slightly hard.

A water with over 20 parts per 100,000 and under 30 parts per 100,000 of hardness may be said to be hard.

A water with over 30 parts per 100,000 of hardness may be said to be very hard or excessively hard.

When the hardness is reduced by boiling, the portion which has disappeared is spoken of as "temporary" hardness, and is due to the carbonates of calcium and magnesium which have been thrown out of solution by the loss of carbonic acid. The hardness remaining is "permanent" hardness, and usually is due to the presence of sulphates of calcium and magnesium, but occasionally to chlorides and nitrates also.

A water in which calcium salts predominate is "calcareous," and if these are chiefly or exclusively carbonates the water is "carbonated." A water in which magnesium salts predominate is a "magnesia" water, and if the chief constituent is magnesium sulphate it is also "sulphated." When sodium chloride is the chief constituent and present in more than usual quantities, the water is usually called "saline," especially if it is associated with other salts of sodium or potassium. A water is said to be "nitrated" slightly, or markedly if nitrates are present in any unusual amount. Where iron is present in an amount discernible by taste the water is "chalybeate" or "ferruginous."

When a water is examined merely to ascertain whether it is wholesome, a subject which will be discussed later, very little information is

required as to the nature of its saline constituents, but when it is required to know whether it is suitable for steam raising or for any particular manufacturing purpose the nature of the saline constituents becomes important. They are also important from another point of view, the scientific one, as the accumulation of analyses will assist in the elucidation of many geological problems, especially those connected with the flow of underground water and the changes which occur in its character. They are especially useful in assisting to predict the character of the water obtainable at any particular place, and the Geological Survey is doing very useful work in publishing all the available analyses in their "County Water Memoirs." These memoirs should always be consulted when a new supply of water is being sought. It would prove a great advantage to water engineers and experts generally if details of the analyses and sources of all the more important water supplies were included in these memoirs, but water authorities are often very loth to give away information which may have cost them large sums to obtain. For this reason, in the Tables of Analyses the exact location of the source of the waters submitted to analysis cannot be given. A study of the analytical results will show how difficult it often is to decide from what particular rock stratum a water has been obtained, and it is not yet generally realised to what extent waters from the same geological stratum may differ in character. One of the most important causes of variation is the nature of the superimposed strata, and another is the distance which the water has had to travel from the outcrop of the water-bearing stratum to the point at which the water is abstracted. These alone do not, however, account for all the variations. A water may issue from a fissure in one kind of rock, and yet really be derived from rocks of an entirely different formation. In Essex many wells are bored into the chalk, and the whole of the water derived therefrom comes from the Thanet sand lying upon the chalk. A well sunk in superficial sands and gravel may yield a hard or soft water, the character depending upon the presence or absence of boulder clay in the vicinity. In some of the drift-covered valleys the superficial springs on one side yield a fairly soft water, whereas on the other side the water may be so impregnated with salts of calcium and magnesium as to be quite unfit for domestic purposes. In the latter case boulder clay will usually be found on the higher ground capping the gravel.

The great majority of the analyses tabulated in Chapter XXV are of waters either used for public supplies, or examined to ascertain if they were suitable for that purpose. The organic purity of most of the waters is indicated by the results of the estimation of the free and albuminoid ammonia, and of the oxygen absorbed in four hours at 80° F.

The silica has only occasionally been estimated, and the "silica, etc.," is merely the difference between the total of the saline constituents estimated and the total solids obtained by drying at 180° C. In some waters peaty matters account for the "etc.," in others suspended

clayey matter, which could not be removed by simple filtration, swells the amount, and, of course, any slight errors in the analyses also affect this quantity.

As previously stated, the study of such analyses may possibly throw some light on geological problems, and stimulate inquiry into the causes of the differences in the character of underground waters. It is fairly certain that no water traverses a permeable stratum without taking up something from that stratum or undergoing some more or less appreciable change. For example, certain of the waters from the Lincolnshire limestone were referred to by Mr. H. Preston, F.G.S., in "Notes on the Geology and Underground Water Supply of South Lincolnshire."¹ He stated, "that the series of analyses prepared by Dr. Thresh are of extreme interest, as they represent samples obtained from typical wells in the Lincolnshire limestone, from its normal condition on the west to its heavily charged condition on the east (as at Crowland) where the rock has thinned out. . . . One result deserves particular attention. The amount of dissolved calcium carbonate decreases from west to east, notwithstanding the longer travel of the water through the limestone rock, whilst the amount of sodium carbonate held in solution increases from east to west. This is shown in graphic form by the diagram" (Fig. 1).

"Now, bearing in mind that the limestone decreases in thickness and becomes more argillaceous as it extends eastward and that the upper and lower Esturine beds are coming closer together, and would probably meet at no great distance east of Crowland, the conclusions forced upon us are that, (1) the water contained in these beds is practically in a dormant condition, and as a consequence has been able to take up from the clay and adjoining beds increasing proportions of sodium carbonate, together with other soluble substances, and

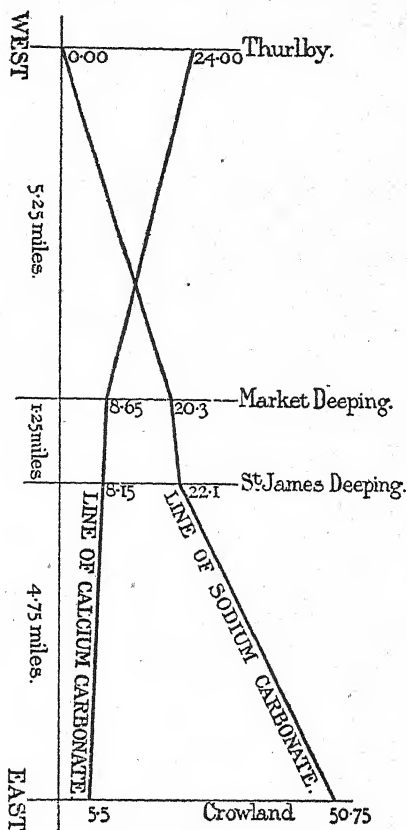


FIG. 1.

¹ Paper read before the Annual Meeting of the Association of Waterworks Engineers, 1903.

(2) that the sodium carbonate has precipitated corresponding amounts of calcium carbonate."

We do not agree with Mr. Preston as to the source of the sodium carbonate. This salt occurs in waters from many different sources, and its origin has been elucidated by the study of numerous analyses and by experiments which are recorded in a paper by Dr. Thresh on "The Alkaline Waters of the London Basin," contributed to the Essex Field Club, and which will be found *in extenso* in the "Geological Memoirs on Essex Waters." The following is abstracted from that paper:—

In 1901 Dr. Thresh published a report on "The Water Supply of the County of Essex," and included therein a map showing that to the east of a curved line passing from Dedham in the north to Barking in the south the waters derived from the chalk (save at the Purfleet outcrop) were "soft" and contained more or less salt and sodium carbonate, whereas on the west of this line the waters had the ordinary character of chalk waters, that is, they contained very little salt and were free from sodium carbonate, but

TABLE I. RESULTS EXPRESSED IN PARTS PER 100,000

Source	1 Chalk. Eton	2 Chalk. Datchet	3 Chalk. Datchet	4 Chalk. Shepherd's Bush	5 London Chalk. Strand	6 London Chalk. Lambeth
Calcium Carbonate .	21.8	16.3	14.7	5.0	3.0	12.75
Calcium Sulphate .	6.4	—	—	—	—	—
Calcium Chloride .	—	—	—	—	—	—
Magnesium Carbonate .	—	3.6	3.1	3.5	2.1	7.85
Magnesium Sulphate .	—	—	—	—	—	—
Magnesium Chloride .	2.3	—	—	—	—	—
Sodium Carbonate .	—	3.4	5.6	21.6	12.8	6.9
Sodium Sulphate .	—	7.6	7.6	24.1	18.1	11.1
Sodium Chloride .	1.1	5.8	5.6	22.6	18.2	14.4
Sodium Nitrate .	3.5	1.3	1.2	—	—	—
Silica, &c. .	1.4	1.4	1.9	.6	1.2	1.0
Total . .	36.5	39.4	39.7	77.4	55.4	54.0
Hardness . . .	30.0	22.0	18.0	8.0	5.0	20.0

contained a considerable quantity of chalk in solution and were therefore "hard." It was also pointed out that in many localities the beds between the base of the London clay and the top of the chalk yielded waters containing an excessive amount of lime and magnesium salts, chiefly sulphates.

In the map above referred to, the dotted line is said to suggest a probable fault in the chalk. In some cases the marked difference in the character of the water, derived from wells not more than, perhaps, one mile apart, seems to indicate the presence of a fault; but there is no other evidence in support of this suggestion, and my further investigations lead me to conclude that it is not necessary to assume the presence of a fault to account for the facts observed.

All the observed results admit of another explanation. So long as the water in the chalk contains carbonic acid it continues to dissolve the chalk

and open out the fissures. When all the acid has been used up in dissolving the calcium carbonate it no longer possesses the power of opening out the fissures, and as the chalk becomes more compressed by the superincumbent mass of sand and clay it becomes so dense as almost to be impervious. Beyond this point, therefore, the water cannot travel in the chalk, and it comes up through the fissured chalk into the sands above and then becomes exposed to their softening action. The compact chalk acts very much like a fault would do, assuming a solid impervious stratum abutting upon a pervious one.

The nature and progress of this change is well exemplified by the analyses of waters taken from various wells sunk into the chalk at Eton, Datchet, Shepherd's Bush, the Strand, and Lambeth, London (see Table I).

TABLE II. RESULTS EXPRESSED IN PARTS PER 100,000

Source	Foxearth	Halstead	Bocking	Braintree	Witham	Billericay
Calcium Carbonate . .	31.0	25.3	21.9	5.3	2.8	1.8
Calcium Sulphate . .	—	—	—	—	—	—
Calcium Chloride . .	—	—	—	—	—	—
Magnesium Carbonate . .	—	2.3	4.4	5.5	1.2	2.8
Magnesium Sulphate . .	6.6	2.9	—	—	—	—
Magnesium Chloride . .	1.6	.2	—	—	—	—
Sodium Carbonate . .	—	—	3.1	19.8	26.7	26.3
Sodium Sulphate . .	—	—	9.0	11.8	10.8	9.4
Sodium Chloride . .	4.5	14.0	28.0	67.2	78.3	36.5
Sodium Nitrate . .	.2	.4	.2	.2	.2	.2
Silica, &c. . .	2.0	.9	1.0	.2	.5	1.0
Total . . .	45.9	46.0	67.6	110.0	120.5	78.0
Hardness . . .	40.0	32.0	26.0	11.0	5.0	5.0

Well No. 1 is on the outcrop of the chalk. The well (No. 2) at Datchet is nearer the chalk outcrop than well No. 3, and the latter therefore has a greater covering of London tertiaries. Wells Nos. 4 and 5 are bored through a considerable thickness of London clay. At Lambeth we are approaching the chalk outcrop in Kent and Surrey.

Note 1. The decrease in the calcium carbonate up to London and its increase towards Kent.

„ 2. The appearance of sodium carbonate and its increase towards London and decrease towards the Southern outcrop.

„ 3. The disappearance of calcium sulphate in the waters under the London clay.

„ 4. The appearance of sodium sulphate in the waters from under the London clay.

„ 5. The increase and decrease in the amount of sodium chloride.

„ 6. The whole series showing a marked change in the character of the chalk water as the distance from the outcrop of the chalk increases.

The next table (II) of analyses includes typical samples of water taken in Essex along a line almost north and south from the bare chalk at Foxearth through Halstead, Bocking, Braintree, Witham, Chelmsford, and Billericay to Grays,¹ where the chalk again outcrops. Note again, the amount of

¹ The Grays water is a typical hard chalk water.

calcium and magnesium salts in the chalk waters at and near the outcrop, the diminution of this amount as the chalk gets deeper, and the corresponding increase in the carbonate and sulphate of sodium, together with the increase in the amount of common salt.

The table shows, however, that whilst the carbonates and sulphates of sodium increase approximately in proportion to the decrease in the corresponding salts of magnesium and calcium, the amount of common salt seems to bear no relation to any of the other constituents. This is better brought out in Table III., which refers to a localised area which has recently had to be studied somewhat fully, viz., the Tendring Hundred, Mersea Island, and the Tollesbury districts. I have analyses of waters from about fifty deep wells in this area, and the salt varies from 23 parts to 180 parts (or probably more) per 100,000, and it will be noted that some of the waters containing least salt are derived from wells near tidal estuaries, whilst many of the waters containing much salt are miles inland. The analyses of certain

TABLE III. RESULTS EXPRESSED IN PARTS PER 100,000

Source	1 10 per cent. Sea Water	2 Chalk. Manning- tree	3 Chalk. Clacton	4 Layer 568 feet	5 Marney 900 feet	6 Mersea
Calcium Carbonate . . .	.8	23.5	5.3	1.4	6.3	5.5
Calcium Sulphate . . .	13.3	—	—	—	—	—
Calcium Chloride . . .	—	—	—	—	—	—
Magnesium Carbonate . .	—	6.5	4.2	.4	3.8	5.2
Magnesium Sulphate . .	21.9	7.2	—	—	—	—
Magnesium Chloride . .	36.7	1.8	—	—	—	—
Sodium Carbonate . . .	—	—	22.0	39.1	29.2	32.5
Sodium Sulphate . . .	—	—	16.1	12.7	12.4	22.9
Sodium Chloride . . .	267.6	22.9	61.7	66.3	144.3	136.8
Sodium Nitrate . . .	—	.2	2.6	.6	—	—
Silica, &c.	—	2.7	2.6	1.5	—	.6
Total	357.0	64.8	114.5	122.0	196.0	203.5
Hardness	abt. 100.0	45.0	11.0	2.0	11.0	12.0

of the waters, however, indicate that tidal water is gaining access. This is well marked in the analysis of the Manningtree waters, No. 2, on Table III. The Geological Survey refers to wells at Ramsey, Pewit Island, Frinton, and other places which yielded brackish water and were apparently abandoned. Dr. Cook, Medical Officer of Health for the Tendring district, informs me that at Walton a well was bored and the water found to become more salt as the depth increased, the figures being :

At 100 feet.	Salt per 100,000 parts of water	257 parts.
At 200 "	"	258 "
At 300 "	"	293 "
At 360 "	"	308 "

A well sunk at Clacton gave me the results No. 3, on Table III. The yield of water was trifling, and upon continuous pumping the water became so brackish that it was abandoned. It will be noted that the water which rose naturally in the bore was comparatively soft, and contained sodium carbonate and no more salt than the deep well waters of Mid-Essex. I am sorry that I did not obtain a sample of the water after continuous pumping,

but the engineer informed me that it was so salt that no analysis was necessary to show that it was too brackish for domestic use.

There is no doubt that in this area the water varies in character at different depths. The salt in the Walton water shows this, as does also the analysis of waters taken from borings recently made at Layer Marney, Nos. 4 and 5, on Table III. The yield at 568 feet was very limited, under 200 gallons per hour, and the boring was continued to 900 feet and blasts of dynamite used, but the yield of water was not materially increased, and the proportion of salt increased to such an extent that the water was useless.

Layer Marney is so far from the sea that it appears difficult to ascribe this increase in the amount of salt to any direct influx of sea water, but my impression is that sea water or tidal water is gaining access to the chalk in

**TABLE IV. RESULTS EXPRESSED IN PARTS PER 100,000
HALSTEAD CHALK WATER + 2 PER CENT. SEA WATER**

Source	1 Untreated	2 Treated	3 Compare with Braintree	4 Further treated	5 Compare with Witham
Calcium Carbonate . . .	27.3	5.3	5.3	2.8	2.8
Calcium Sulphate . . .	1.8	—	—	—	—
Calcium Chloride . . .	—	—	—	—	—
Magnesium Carbonate . . .	—	5.5	5.5	1.4	1.2
Magnesium Sulphate . . .	8.0	—	—	—	—
Magnesium Chloride . . .	9.8	—	—	—	—
Sodium Carbonate . . .	—	16.7	19.8	25.2	26.7
Sodium Sulphate . . .	—	11.4	11.9	11.4	10.8
Sodium Chloride . . .	63.3	75.2	67.2	75.2	78.3
Sodium Nitrate . . .	.3	.8	.2	.2	.3
Silica, &c.	1.0	1.1	1.2	1.3	.4
Total	111.5	115.5	111.1	117.5	120.5
Hardness	—	12.0	12.0	5.0	5.0

the Thorpe-le-Soken area, and at and near the chalk outcrop in the Stour Valley. The proof that these saline waters are derived from an admixture of sea water and chalk water is, I think, proved by the analyses of mixtures of chalk water and sea water after passing through a filtering medium which can remove the calcium and magnesium salts more or less completely, substituting sodium and potassium in their place. The mere proximity to the sea does not enable anyone to say whether a water will be salt or not, as a well near the coast may or may not contain an excessive amount of salt. For example, compare typical waters from Brightlingsea with those from Mersea Island and Tollesbury.

I have made several experiments with mixtures of sea water and chalk water to show the effect of the softening process which I shall describe presently, and Table IV is designed to show how the various waters in the London basin can be imitated by mixing chalk water with sea water and then submitting them to this peculiar treatment.

Table IV shows how a mixture of 2 per cent. of sea water with 98 per cent. of chalk water from Halstead would be altered by filtration through different thicknesses of sand.

Braintree is about half-way between Halstead and Witham. Assume

that the water in the chalk at Halstead becomes mixed with 2 per cent. of sea water on its way to Braintree and at the same time is traversing the Thanet sands and becoming softened. Then the result at one stage would be the water (2) which, as will be seen, bears the closest possible resemblance to the Braintree water (3). Travelling onwards towards Witham the water would become still softer, more of the calcium and magnesium salts being removed, and at some point a water having the composition of No. 4 would result, and this, it will be noted, bears the closest resemblance to the Witham water No. 5.

Towards Chelmsford the water would become still softer, which is actually the case, but as the water in the Chelmsford area contains a little less salt we have to suppose that dilution with a less saline water is taking place, probably from the neighbourhood of Saffron Walden. By varying the source of the chalk water and the proportion of sea water, I think every water from the chalk and Thanet sands in the county of Essex and under London could be imitated.

TABLE V. LONDON CHALK WATERS EXPRESSED IN PARTS PER 100,000

Source	E.C.	Calendonian Road	Clement's Inn	King's Cross	Charing Cross	Millwall
Calcium Carbonate . . .	4.4	4.0	4.4	3.4	4.0	27.6
Calcium Sulphate . . .	—	—	—	—	—	21.5
Calcium Chloride . . .	—	—	—	—	—	46.8
Magnesium Carbonate . . .	3.5	2.8	2.3	1.9	2.5	—
Magnesium Sulphate . . .	—	—	—	—	—	—
Magnesium Chloride . . .	—	—	—	—	—	15.2
Sodium Carbonate . . .	18.0	19.1	21.4	21.8	18.4	—
Sodium Sulphate . . .	20.1	20.0	23.2	21.9	24.8	—
Sodium Chloride . . .	16.0	16.7	23.6	17.9	30.3	182.7
Sodium Nitrate . . .	.3	.6	.2	.3	.3	.2
Silica, &c.	1.0	.4	.4	.5	1.2	.2
Total	63.3	63.6	75.5	67.7	81.5	291.2
Hardness	9.0	7.0	8.0	6.0	7.0	100.0

Assuming that the salinity is due to sea water, then the bromides which exist in sea water would be capable of detection in the saline waters. This proved to be the case.

The proportion of bromides to chlorides is much the same as in sea water, whether the saline water contains much salt, as the Barking water, or little salt, like the Chelmsford water.

Table V shows the saline constituents of typical waters derived from deep wells in London. It will be observed that most of them are of the alkaline type, but that the proportions of the constituents vary. Nearly all indicate the admixture of a very small amount of sea water with the chalk water prior to it having undergone the softening process. Others derived from the chalk near the river show the presence of unchanged tidal water, as at Millwall.

The results of these experiments and others quoted in the original paper show—

1. That the Thanet sand from beneath the London clay possesses the power of softening hard water, by substituting sodium (and possibly potassium) salts for those of calcium and magnesium.

2. That the constituent to which this softening effect is due is not removed by treatment of the sand with dilute acid, but appears to be removed by treatment with strong hydrochloric acid.
3. That this property of softening water belongs both to the clayey and sandy matters.
4. That the softening effect is greatly increased by treating the sand with brine.
5. That the amount of alkali removable by this softening effect is only a small proportion of the total alkalies contained in the sand.
6. That (within certain limits) a sand which has ceased to soften a water of a certain degree of hardness will exert a softening effect upon a water of a greater degree of hardness, and will exert a hardening effect upon a water of a softer character.

(In other words, the process is a reversible one.)

This paper is quoted somewhat fully in the hope that someone may be sufficiently interested to follow up the experiments, or conduct experiments on similar lines to elucidate some of the problems relating to the origin of the constituents of underground waters. The results show that chemistry can, in certain cases, throw light also upon the direction of flow of such waters, but for this purpose the analyses must be much more full than those usually made for sanitary purposes.

Hitherto the estimation of the saline constituents of a water has been a difficult and tedious process, hence the paucity of such analyses. Now that sufficiently accurate, yet rapid and comparatively simple, processes have been devised, it is to be hoped that other chemists will make a special study of the peculiarities of waters from different geological sources.

The results of the examination of many samples of water, together with the geological formation from which each was derived and the locality from which obtained, will be found in Chapter XXV.

PART II

CHAPTER IV

EXAMINATION OF THE SOURCES OF SURFACE WATER SUPPLIES

SINCE the introduction of improved methods of purification, such as chlorination and mechanical filtration, etc., many surface sources of water supply will be used in the future which would until recently have been considered unsafe.

In examining surface water sources, therefore, it is not only necessary to discover all the possible sources of pollution, but also to consider whether such sources can be excluded completely, or, failing this, to determine whether the polluting matter can be rendered harmless. The extent of the catchment area will be delineated by the engineers from a study of the ordnance maps and actual observations. The ideal area is one actually owned by the water authority, or one over which they have acquired complete control of the surface (as by bye-laws), or upon which there are few or no inhabitants, the minimum amount of land under cultivation, no factories or works, and no roads or footpaths.

In this country there are few upland surfaces reasonably free from the possibility of pollution, and in most areas it is impossible for the authority to obtain control of the whole watershed. Even the question of mineral rights has to be considered. There may be coal or other minerals under the area, and the possibility of mines being sunk. In such cases the question of land subsidence has to be taken into consideration as well as the increased risk of pollution from the advent of a mining community. In other cases quarries of stone or slate may be established, which would lead to increased traffic and probably to an increased population. Before commencing the examination, therefore, it is well to bear these possibilities in mind, as a Parliamentary Committee will not pay much attention to evidence unless the witness has not only considered existing conditions, but also conditions likely to obtain within the next generation. A drive through and round the area will give a bird's-eye view and enable a decision to be arrived at as to the points which require careful examination. Usually it is well to start at the reservoir, or the site of the proposed reservoir, find the position of every rivulet which will feed it, and note their position relative to the outlet. Cases have been found in which the largest and most

polluted tributaries entered the reservoir so near the outlet that within about an hour the contaminated water would enter the mains.

These impounding reservoirs may hold several months' supplies of water, but if polluted tributaries are near the point where the water is withdrawn, the water therefrom may not be stored in the reservoir a sufficient time for the purifying effects of storage to be of any value.

Samples of water should be collected for analysis from every tributary. Bacteriological examinations will help in forming an opinion with reference to its purity or otherwise. Then, starting from the reservoir, the streams can be followed up to their sources.

The drainage area of every cottage, house, or farm, should be examined to discover what ultimately becomes of the sewage, whether it pollutes the reservoir directly (cesspools have been found outflowing directly into reservoirs) or indirectly through some rivulet, or whether it is or can be carried by some sewer beyond the boundary of the collecting area. The land under cultivation, if any, should be visited to ascertain whether manure or sewage is applied to it, and especially if pail closet or privy cesspit contents, or imported house refuse, are spread upon it.

This investigation should be supplemented by chemical and bacteriological examination of further samples of water taken from the various feeders both in dry and wet weather. The late Professor Delepine laid considerable stress on the importance of bacteriological examinations. As there is no general standard of purity, he selected feeders which were uncontaminated, examined the water bacteriologically, and regarded the results as a "natural standard." "To find such feeders," he stated, "the bacteriologist of course inspects the gathering ground himself, and after noting the configuration and nature of the ground, the course of the feeder, its relation to the slope which it drains, the absence or presence of cultivated areas, of paths, of houses, the possibilities of human traffic, the presence of cattle or sheep, he can then determine whether the feeder inspected is likely to be contaminated or not. . . . It is necessarily free from any bacteria associated with decomposing organic matter, human or animal diseases (providing no carcase of a dead animal is found in its neighbourhood). Such a water should be good, assuming no abnormal chemical constituents are present. Even under these conditions water is liable to variations, according to the state of the weather; during heavy rains it becomes mixed with surface soil and decayed vegetable matter, washed down from the surrounding slopes or carried away from the banks of the brook itself. Consequently, during and after stormy weather, even the water of a pure feeder contains a much larger number of bacteria than it would contain when the weather is fine and the stream is running smoothly. This increase of bacteria, which is not excessive when the surface soil is of a suitable nature, does not render the water dangerous to health. Knowing the number and the kind of bacteria normally present in two or three uncontaminated feeders both during

fine and rainy weather, one would therefore have standards by which to test the water collected on any other parts of the gathering ground or taken from reservoirs within the limits of the same supply."¹

By this method Professor Delepine has traced sources of pollution which had been overlooked by the persons who inspected the watersheds. One cannot help thinking, however, that had a fraction of the time spent on the bacteriological examinations been devoted by a competent person to examining the collecting areas, the pollution would have been discovered. Yet as a supplement to such a thorough examination of the various sources of the water, the bacteriological examinations are most important. If the bacteriological results are satisfactory and confirm the results of inspection, the evidence in favour of the safety of the water is probably as conclusive as it can be made. If, on the other hand, the bacteriological examination indicates contamination of some feeder, a further inspection must be made to ascertain if any source of pollution has been overlooked. A concealed drain may be discovered, or a dead animal may be found undergoing putrefaction in the stream.

Chemical analyses are not of great importance in such investigations, but the survey would not be complete without analyses of each of the main feeders. Surface water usually contains a very perceptible trace of vegetable matter, and may, in fact, be more or less discoloured by peat, and in such waters a small amount of sewage is tolerably certain to be overlooked, even upon the most careful chemical analysis.

Moorland gathering grounds require special examination, to ascertain the extent of the area covered with grass, heather, bracken, bilberries and bog moss and the presence and extent of peat bogs. Peat occurs chiefly on the igneous and oldest rocks, the Cambrian, Silurian, and Devonian formations, and on the rocks of the coal measures. Water which has been in contact with peat and the rootlets of plants which form peat, becomes acid, the acid apparently being of an organic nature, and the longer it remains in the peat the more acid it becomes. Such waters possess the power of dissolving lead, the plumbo-solvent power depending chiefly upon the amount of acid present. It may be found possible to cut off limited areas furnishing such acid waters, or springs may be detected yielding water containing sufficient carbonates and silicates to neutralise the acids in the peaty water. By examining the streams draining different portions of the collecting area, information will be gained as to the character of the water from each portion. Although in dry weather such water may be neutral in reaction and have little or no action upon lead, owing to neutralisation of acidity by access of spring water, yet in rainy weather the same streams may yield waters with a markedly acid reaction, due to the preponderance of surface water from peaty ground. As the dry-weather flow may be comparatively small, the bulk of the water collected in reservoirs will be acid. Heavy storms wash out of the peat-bogs water which has long been in contact with the peat and has

¹ *Journal of State Medicine*, vol. vi., pp. 145, 193, 241, 289.

a marked acid reaction. Sir Alexander Houston recommended in the case of proposed new reservoirs for the collection of moorland water, "a careful survey of the physical characters of the gathering grounds, as well as the ascertaining of the proportion of spring water to surface water at different times of the year and under different conditions of rainfall, and the testing of the quality of the spring water and its power of neutralising acid, and the quality of the surface water, especially during wet weather and sudden storms following a period of drought."

On land already utilised and yielding acid waters, there is no doubt that in many cases the quality of the water could be improved by excluding special areas, and arranging to discard or neutralise the extremely acid waters, which would otherwise enter the reservoirs at the commencement of heavy storms. When the collection of an acid water cannot be avoided, treatment for the neutralisation of acidity should be arranged, otherwise the consumers run the risk of lead poisoning where the water is conveyed from the mains to the houses through lead pipes. If the observer carries with him a little solution of bromo-thymol-blue, he can tell in an instant whether a water is acid, neutral, or alkaline, by pouring a few drops into the stream.

In examining surface water supplies, the position of the impounding reservoirs and the condition of their immediate surroundings require special attention. The land adjacent to reservoirs, and the banks of feeders, should not be cultivated, and should be so protected by fencing as to prevent cattle gaining access. There are collecting areas in this country on which exist villages with churches and burial grounds, and in one case a large school was situated within a few yards of a reservoir into which the sewage from the school indirectly discharged. If reservoirs in such positions must continue to be used, there should be an efficient system to carry the sewage outside the collecting area, or to a point where the whole could be properly purified.

Cases also are on record of house refuse and the contents of pail closets being used as manure on land abutting on reservoirs, and of paper and dust therefrom, blown about by the wind in dry weather, being seen floating on the surface of the water.

Footpaths or highways along the banks of reservoirs are objectionable, since they permit of many forms of wilful or accidental pollution. If the ground around, sloping to the reservoir, cannot be kept absolutely free from manurial matter, it should be drained so that neither surface nor subsoil water, from portions so treated, can gain access to the reservoir.

The shallower parts of a reservoir may become exposed during dry seasons, in which case the growth of low forms of vegetable life is encouraged and may result in the whole water supply being infected.

Where a natural lake has been converted into a storage reservoir, it may be found that boats ply for hire thereon, or there may be a regular service of steamers, as on Loch Katrine. If such is the case the

boats should be under the control of the authority and stringent regulations enforced to prevent pollution.

By-passes should be provided to carry away very turbid storm waters, and the reservoirs should be sufficiently large to tide over the longest drought. In prolonged dry weather when the water in the reservoir gets low, vegetable growths may occur and injuriously affect the character of the water. The position of the outlet should be noted, and the farther this is from any inlet the better, since areas of stagnation are avoided, and there is less danger of water from any feeder passing direct to the outlet without undergoing that purification which proper and adequate storage affords.

It is probable that no surface water can be considered entirely satisfactory if not carefully filtered before distribution. There may be no danger of pollution from sewage or manure, but low forms of vegetable and animal life occasionally become very prevalent, and floods may cause turbidity. Where such unfiltered waters are supplied there are frequent complaints, especially during the summer months, of unsightly appearance or disagreeable odours. Organisms which are not visible at the time of delivery may multiply so rapidly afterwards that vessels in which the water is allowed to stand for a day or two become coated with a slimy deposit, or with a distinct green growth. Any method adopted for straining or filtering the water should therefore be carefully inspected. The wire gauze arrangements so often used are not sufficient to prevent the lower forms of animal and vegetable life getting into the mains. The reservoirs and the whole of the collecting area should be under constant supervision, since a dead body in the reservoir or on the watershed does not improve the quality of the water.

On some collecting areas, especially in South Wales, where the rocks are highly fissured, springs of large volume occur, and it does not always follow that the water issuing therefrom is collected upon the area under examination. Cases are recorded of such springs being traced to adjacent valleys where the water was liable to serious pollution. Often the source cannot be discovered, and it may require continual observation and repeated examinations to determine where the water is liable to serious changes in quality.

In view of the efficiency of modern purification methods, and when the flow of water is adequate at all times, it is sometimes practicable, and more economical, to abstract water from the lower reaches of a river instead of resorting to the head-waters. The high costs of constructing large impounding reservoirs for storage and compensation, and of aqueducts and pipe-lines, may thus be avoided, and existing amenities and water rights above the intake preserved. With the formation of active River Boards controlling watersheds as a whole, and with the further prevention of pollution, there would be more opportunities for such intakes, and the need for them will surely increase. As will be subsequently described, river waters, if not unduly polluted, can be adequately purified for public supply purposes, and, if desired, they can, in many instances, be economically softened.

The introduction to the L.G.B. report on "Water Undertakings" makes the following reference to the importance of examination of the sources of supply and the value of chemical and bacteriological examinations when properly made :—

"The freedom of a water supply from danger of pollution, and from the consequent risk of producing disease, can only be determined by close topographical examination of its sources. Its actual quality can best be judged by the results of chemical and bacteriological examination, and in every case in which the water was subjected to such examination the Board endeavoured to obtain a copy of the latest analysis made. A brief summary of the results of these analyses has been inserted in the return to illustrate the quality of the water; the copies of the analyses have been retained by the Board amongst their records. In some cases in which the water is only occasionally examined the last analysis is too old to be of value. In other cases the details of the analysis were given without any comment by the analyst on the quality of the water, and in the absence of information as to the circumstances in which the sample analysed was taken it has been considered inadvisable to insert in the return an opinion on the figures of the analysis. From the return it appears that the quality of the water supplied, in some cases from one particular source amongst several, by twenty-six local authorities and two joint authorities is not satisfactory, whilst that supplied by five other local authorities is liable to pollution.

"(1) Uplands Surfaces. Many undertakers rely upon water collected in reservoirs from the surface of uncultivated land, and such sources have been described in the returns as 'upland surfaces,' 'gathering grounds,' or 'drainage areas.' In some cases it is not possible to differentiate between supplies derived from upland surfaces and from rivers, streams, lakes and springs, but it would appear that 136 local authorities, eleven joint authorities, and twenty companies depend upon gathering grounds for the whole or part of their supplies. Among the more important of these are the local authorities of Blackburn, Halifax and Huddersfield, with available supplies per day of 20,973,950 gallons, 13,500,000 gallons, and 9,750,000 gallons respectively, and the Bury and District Joint Water Board, which obtains 5,962,000 gallons per day. Some undertakings with other sources derive very large quantities of water from gathering grounds, but the quantities obtained from the various sources are not always given. The local authorities include Leeds and Sheffield with available supplies per day of 30,662,025 gallons and 14,883,610 gallons (minimum estimate), and Oldham, which obtains 5,274,000 gallons per day. The Pontypridd and Rhondda Joint Water Board obtains 3,123,785 gallons per day.

"(2) Lakes. The principal natural lakes of England and Wales are situated in Cumberland, Westmorland and North Wales, and some of these have been laid under contribution for purposes of water supply. The Royal Commission appointed in 1866 to ascertain what supply of unpolluted and wholesome water could be obtained by 'collecting and storing water in the high grounds of England and Wales either by the aid of natural lakes or by artificial reservoirs, etc.,' considered a plan to provide the metropolis with water from Thirlmere, Ullswater, and Haweswater, with an additional supply from Bala Lake in Merionethshire. The Commissioners made an independent investigation of the quality of the water from the lakes, and found it excellent as regards softness and purity, freedom from mineral contents and organic contamination, but slightly coloured with peat. They rejected the plan partly on this latter ground, and partly because of the uncertainty of the cost, the possible stoppage of flow in the conduit, the necessity of pumping, and the consideration that the sources of supply belong geographically to the large and increasing population in the north of England.

"In 1878 Lake Thirlmere was appropriated by the Corporation of Manchester by a Bill which was considered by a Select Committee of the House of

Commons. They reported that the lake was a particularly favourable source of supply because of the large rainfall (about 100 inches annually), the scant population in the vicinity, and the consequent abundance and purity of the water to be derived from it, and because its elevation and situation were favourable for affording a gravitation supply to Manchester. The corporation were authorised to take 50,000,000 gallons a day from the lake. At the end of 1913 they took, according to their returns, 17,800,000 gallons a day.

"Lake Vyrnwy now affords a supply of water to Liverpool, Crummock Lake to Workington, Haweswater to Penrith and Ennerdale Lake to Whitehaven.

"Quality of Water from Upland Surfaces. The purity of water derived from these sources depends upon the freedom of the gathering grounds from contamination from human habitations, farm buildings, and live stock. The Committee of British Forestry, which reported in 1902, drew the attention of local authorities deriving their water supplies from gathering grounds owned by them to the advantages and profits to be derived from planting the catchment areas with trees, not only to contribute to the retention of the rain and assist in regulating the water supply but to help to purify the water, and at the same time to yield a regular income on the capital expended. In connection with this report the Local Government Board obtained a return in 1903 showing which of the local authorities owning waterworks had acquired the freehold or long leasehold of the catchment areas from which their water supplies were derived. This return, which was not published, showed that at that time five joint boards and seventy-four town and district councils owned or had a long lease of a part or all of their gathering grounds."

In later chapters will be found analyses of surface waters from many parts of the United Kingdom.

CHAPTER V

EXAMINATION OF RIVERS AND STREAMS

RIVERS and streams are fed by surface, subsoil, and spring waters. The complete inspection of a river involves the examination of practically the whole of the watershed above the intake, covering an area, in some cases, of hundreds of square miles. There may be a very large population on the watershed residing in towns and villages, besides scattered houses, farms, manufactories, mines, etc., all draining directly or indirectly into the river, and there may be a floating population on the river itself. A certain portion, possibly nearly all, of the land, may be under cultivation, and more or less highly manured. In such cases pollution is inevitable, and many sanitarians hold that water from such a stream cannot under any circumstances be a satisfactory source of supply. Those who are interested in this subject should study carefully the evidence given before the Royal Commission appointed to inquire into the water supply of the Metropolis, and also their report published in 1893. Here the Rivers Thames and Lee were under consideration, the former with a population of over one million persons in the valley above the intake of the water companies and the latter with a population of about 200,000.¹ The pollution of the rivers is admitted, as is also the fact that some of the infective substances given off by persons suffering from zymotic diseases find their way into the rivers. The following quotation gives briefly the opinions of the Commissioners and the reasons upon which they based their conclusions :—

“That the amount of such (infective) substances that thus enter the Thames and the Lee is extremely small, and indeed infinitesimal in proportion to the enormous bulk of water with which it is then mixed, that there are, moreover, numerous conditions which lead to the destruction or elimination of the pathogenic bacteria during the flow down the stream, and afterwards during the sojourn of the water in the subsidence tanks and during the process of filtration : so that it is extremely doubtful, to say the least, whether a single one of these pathogenic bacteria will remain in the water as delivered to the consumer, or even in the unfiltered river water itself, that in spite of frequent examinations none have ever been detected in it, and that even on the improbable assumption that some few might exceptionally pass through the successive barriers to their entrance into the service pipes, they could not possibly be there in such number as to give rise to disease,

¹ The populations are now considerably greater, yet the water supplied was never so satisfactory as at present. It should, however, be remarked that the water is now chlorinated.

which, according to all bacteriological researches, requires a certain quantity of such bacteria for its production."

If the above conclusions are accepted, the chief points to be considered in investigating a river supply are :—

1. The relative proportions of the polluting matter and the flow of the river when at its minimum.

2. The general character of the stream, the rate of flow, and the distance between the sources of pollution and the intake of the water.

3. The sufficiency of storage to allow of properly purified water being distributed during periods of flood when the river water is turbid.

4. The efficiency of the subsequent storage and filtration or system of purification adopted.

The Commissioners who considered all these points in connection with the Thames and the Lee state in the final section of their report : " We are strongly of opinion that the water, as supplied to the consumer in London, is of a very high standard of purity and excellence, and that it is suitable in quality for all household purposes. We are well aware that a certain prejudice exists against the use of drinking water derived from the Thames and Lee, because these rivers are liable to pollution, however perfect the subsequent purification either by natural or artificial means may be, but having regard to the experience of London during the last thirty years, and to the evidence given to us on the subject, we do not believe that any danger exists of the spread of disease by the use of this water, provided that there is adequate storage, and that the water is efficiently filtered before delivery to the consumers." Subsequent experience has confirmed these views.

As a general rule, rivers are inspected with the view to detecting sources of pollution in order to secure their removal. The stream should be carefully followed up and every tributary, drain, and ditch connected therewith noted, as well as the extent and character of the areas liable to flood, and the proximity of highly manured land, sewage works, and manufactories. Samples of all liquids being discharged therein, and of the river water at different points, should be taken and submitted to chemical and bacteriological examination. The possibility of sewers discharging under the surface, for the purpose of concealment, should not be forgotten, nor should the fact be overlooked that sewage may accumulate in ditches during dry seasons and the whole be washed into the river with the first heavy rainfall. The amount of dissolved oxygen found in the water taken at different points may furnish valuable information as to the rapidity with which the process of self-purification is taking place. A report on the condition of the River Severn, prepared by the late Professor Boyce for the Royal Commission on Sewage Disposal, and contained in the interim report, touches on several points connected with river examination, and is worth perusal by any one interested in the condition of our streams. The detection of all the sources of pollution in a river of any length is a matter of very considerable difficulty. Even if the whole length of the banks on both sides is examined, some intermittent or even continuous source of con-

tamination may be overlooked. Chemical and bacteriological examinations of the water may in such cases lead to further investigation and the discovery of the cause of pollution. For example, when examining an Essex river, we suspected that between two given points some polluting matter, the source of which we had failed to discover, was entering the stream. A further survey revealed the fact that the sewage from a large group of houses was conveyed to a tank in a field, and was supposed to be disposed of by broad irrigation. The tenant of the land, instead of so treating the sewage, had cut a grip across the field which conveyed the raw sewage directly into the river. It entered through an opening in some dense brushwood, and could not be seen from the banks.

As the discharge of improperly treated sewage into streams is illegal, the person inspecting must have an intimate knowledge of the various processes of sewage purification, so as to be able to say whether the works are of such a character as to deal in the most effective manner with the sewage, both in dry and wet weather. Such works should also be subject to constant and rigorous supervision. Unfortunately the most modern methods of sewage disposal fail to remove a large proportion of the bacteria in the sewage, including those belonging to the coli group. Where a sufficient area of suitable land is available, an effluent of greater bacterial purity can be obtained than has yet been effected by treatment of sewage on bacteria beds only, but effluents obtained by double treatment from beds upon which the sewage was spread by modern sprinkling arrangement are little inferior to those obtained by land treatment. Where barges, boats, etc., ply upon a river from which water is taken for the supply of any community, power should be obtained to make regulations for preventing pollution by the pumping out of bilge water or the casting of refuse into the stream.

The formation of local Rivers Boards under a Central Board, as suggested by the Royal Commission on Sewage Disposal, if carried into effect, will probably result in such Boards being given greatly increased powers for the prevention of pollution of rivers and sources of water supply generally.

In many localities rivers are more polluted by effluents from manufactories, quarries, mines, etc., than by sewage. It should be ascertained whether there is any infringement of the Rivers Pollution Prevention Act, either by the casting in of solid refuse, or the inflow of liquid effluents. This implies a knowledge of the best practical means of purifying trade-wastes of the most diverse character, and, as in the case of sewage works, the exercise of constant supervision to see that the best means of purification have been adopted, and that they are properly used. The existence of by-passes permitting untreated, or partially treated sewage, or manufacturers' refuse, to be conveyed to the river must always be regarded with suspicion, and, if possible, steps should be taken to secure their removal. Every gasworks should be visited to ascertain what becomes of the spent liquors. They are often conveyed surreptitiously into the nearest stream.

But when everything possible has been done to secure the most efficient purification of such waste products, rivers receiving sewage and trade effluents can only be regarded as possible sources of water supply when no purer source is reasonably available. The arrangements for collecting the water, for storage, purification and filtration, should receive special attention. The storage reservoirs provided should be so large as to admit of a supply of purified water being maintained during periods of heavy rainfall without any water being taken from the river whilst it is in a turbid condition. In any case, at the height of a flood the water, which will contain all the washings from ditches, and possibly all the sewage from the various works within the drainage area, and much of the mud from the bed of the river, should not be collected. The admission of such turbid and polluted water would defile all the water in the storage reservoirs for a considerable period.

Trade waste, like sewage, requires purification before being discharged into streams.

Save near their sources, rivers cannot be expected to yield water which has escaped contamination, but the experience of London, supplied with water from the Thames and Lee, both containing a considerable amount of sewage effluent, land drainage, etc., shows that a well-supervised river will yield water which by storage and filtration can be converted into a perfectly wholesome water. With chlorination or excess lime treatment the storage can be greatly reduced, if the river water is excluded during, and for a day or two after, the onset of a flood or very heavy rainfall. With excess lime the storage can be reduced to a very few days, the number depending upon the effect of heavy rainfalls upon the particular river. However, where sources of pollution can be removed at a reasonable cost, this should be done; where the cost would be excessive, the sewage or other effluent should be submitted to a purification process producing the best possible results. The greater the distance between the entrance of an effluent and the intake of a waterworks the better, since a flow of a few miles usually leads to a marked improvement in the condition of the river.

Vol. II. Appendix of the Eighth Report of the Royal Commission on Sewage Disposal contains a great deal of information on this subject.

The Commission suggested that just below the outfall the mixture of effluent and river water should not take up in five days more than 0.4 part of dissolved oxygen per 100,000. If this standard were generally adopted, our rivers would in many cases be markedly improved in condition, as a river water absorbing less than 0.4 part of dissolved oxygen can be efficiently purified, assuming there are no sewage or other works discharging injurious matter, whether in solution or suspension, for some miles above the intake.

Different authorities adopt different standards for effluents, few, if any, paying any regard to the condition of the stream above the point of discharge of the effluents. In such cases, all that can be done is to see that these standards are complied with. If, however, the oxygen

absorbed at a proposed intake exceeds 0.4 part per 100,000, the water is not suitable for purification. If it is generally under 0.4, and only exceeds this on rare occasions, it may be utilised, arrangements being made to exclude the river water when this amount is exceeded. Prolonged daily observations will enable an opinion to be formed with reference to the amount of storage required to tide over these intervals.

Where trade waters are being discharged, not only should the oxygen test be complied with, but suspended matter should be very small, and the colour, odour, turbidity, and reaction of the river water should not be affected.

The methods to be adopted to secure the proper purification of sewage and trade waste are so numerous that they cannot be dealt with here, and they come within the province of the sewage works engineer rather than of the chemist and bacteriologist. Trade wastes are dealt with in the Ninth Report of the Royal Commission on Sewage Disposal, Vol. I.

The Commission classified the waters of rivers according to their power of absorbing oxygen from solution, but many chemists prefer to estimate the oxygen absorbed from permanganate, as the latter can be done in five hours whilst the former requires five days.

ROYAL COMMISSION CLASSIFICATION

Very clean river waters absorb under	0.1	parts of oxygen per 100,000		
Clean river waters absorb under	0.2	"	"	"
Fairly clean river waters absorb under	0.3	"	"	"
Doubtful river waters absorb under	0.5	"	"	"
Bad river waters absorb over	0.5	"	"	"

The subject of our rivers as sources of supply is one of such great importance that the evidence prepared to support the Chelmsford Water Bill in Parliament (1922-3) is quoted below. Fortunately for the ratepayers of the borough, the Bill was approved by the Ministry of Health and was not opposed, hence the evidence was not published.

The River Chelmer at the proposed point of intake has a daily flow averaging 10,000,000 gallons, but falling in very dry seasons to little more than 2,000,000 gallons. The average amount to be taken daily is 1,000,000 gallons. Below the point of intake there is only one mill which it could be alleged would be affected, and the owner was satisfied when informed that all the water abstracted would be discharged as effluent at a point well above his mill.

The following abstract from Dr. Thresh's proof of evidence shows why the use of water from such a river was approved by the Ministry of Health and by Parliament :—

" Having made a special study of the various sources from which water can be derived in Essex, he came to the conclusion some years ago and reported to the county council that if the population was to go on increasing the time would soon come when the waters from the Essex rivers would have to be utilised. In consequence he has paid special attention to the rivers and especially to those in Central Essex which would be most likely to be called upon to furnish such supplies.

Chelmsford is in the very centre of Essex, and the increase in population renders it imperative that the water supply to the town should be increased as soon as possible, as the present sources do not suffice to maintain a constant supply. The only possible sources from which water can be obtained in any quantity are (1) deep wells sunk into the sands overlying the chalk and (2) the River Chelmer flowing through the town.

Deep well waters would be preferable, but unfortunately this source is being depleted. The town possesses three deep wells and is surrounded on every side by deep wells from which water is now being pumped faster than it can be replenished by the rainfall. Consequently the level of the water is falling every year and the yield diminishing. To provide another 500,000 gallons of water a day would require the sinking of five or six more deep wells, and as these would have to be at least a mile and a half from each other, and from existing deep wells, the cost of making and connecting and of maintaining five or six additional pumping stations is so great that it is beyond the power of the town to bear such a financial burden.

There is, therefore, no choice; there is no other available source than the River Chelmer. This river rises at Wimbish beyond Thaxted about twenty-five miles N.N.W. of Chelmsford and near Chelmsford receives a large tributary, the Can, a river which rises in the Roothings and which, about a mile above Chelmsford, is joined by the River Wid, which rises east of Ongar.

The total drainage area of the Chelmer above the proposed intake is about 158 square miles. Along the valleys a considerable amount of gravel is exposed, save in the Wid area. Beyond the gravel, the soil is practically all boulder clay. The boulder clay is not very pervious, but it absorbs a considerable amount of water, and much of what runs off runs over the gravel beds, which absorb water much more freely. In dry seasons the river is fed by the water running from the gravel beds; in wet seasons much of the water must be derived chiefly from the surface, but as the water continues to be 'very hard,' even in the wet season, the great bulk of the water must still be derived from the gravel and boulder clay.

The whole of the drainage area is under cultivation, just as is the land in the Thames and Lee valleys. He estimates that in the Chelmer area there is a population now of 55,000, giving 350 persons per square mile. This includes the borough of Chelmsford, which is to be effectually cut off from the river. Population; 20,761. The sewage works are down the Chelmer Valley, below the proposed intake. Without Chelmsford, the population per square mile is only 200. In 1893 the population in the Thames Valley was 300 per square mile, and in the Lee Valley 448. There can be no doubt, therefore, that at the present time the population per square mile will not exceed that in the Thames Valley, and is much less than in the Lee Valley; consequently, so far as the population draining into the river is concerned, the Chelmer is no worse than the Thames, and much better than the Lee, the two rivers which supply London and a large area around. When Chelmsford is cut out the Chelmer Valley will be far better than the Thames, and it is believed that the water will be better. He has, during the last twenty years, examined a large number of waters taken from the Thames, the Lee and the Chelmer. After carefully studying the results he concludes that in dry seasons the River Chelmer water is as good as either, but that in periods of heavy rainfall, whilst it is as good as the Lee water, it is not quite so good as the Thames. For this reason he recommends that during heavy rainfall no water should be abstracted from the Chelmer for the purposes of water supply.

The Royal Commission on Sewage Disposal, who gauged the river, frequently said that the flow of water in the Chelmer throughout the whole year averaged 12,000,000 to 13,000,000 gallons. One inch of rainfall upon a square mile yields about 14,500,000 gallons. The total rainfall on the

whole drainage area of 158 square miles in an average year would be over 50,000 million gallons, whilst the flow down the river would be 4,380 millions, or only about $8\frac{1}{2}$ per cent. of the rainfall. More than this must certainly get into the river, hence probably the flow during floods and heavy rainfalls is not included. The results show, however, that the amount proposed to be taken by this Bill is but a very small proportion of the average flow.

A chart prepared from the rainfall records from 1876 to 1910 shows that

6.6 per cent. falls in January.			9.8 per cent. falls in July.		
6.7	"	February.	10.1	"	August.
7.2	"	March.	8.0	"	September.
6.2	"	April.	10.8	"	October.
6.8	"	May.	9.9	"	November.
8.7	"	June.	9.2	"	December.

This is important as showing that the period of heaviest rainfall is usually from July to December, or for the months of late summer and early autumn when most water is likely to be required.

He has examined the river repeatedly from its various sources down to the Blackwater estuary, and has analysed hundreds of samples therefrom.

On June 16th, 1921, he took samples, ten in all, at different points between and including its source above Thaxted and Sandford Mill below Chelmsford. The water at the lowest point was nearly as good as at its origin. This is due to two factors chiefly :—

1. Sedimentation. The flow is sluggish and suspended matters deposit rapidly.

2. Self-purification effected by exposure to air and light. The river is nowhere of any depth, and the organic matter washed in, whether as sewage or as surface water from cultivated land, is rapidly oxidised. Bacteria of an objectionable type are out of their proper environment when in water, and they die out rapidly. Numerous recorded experiments made by himself and others, especially by Sir A. Houston, of the Metropolitan Water Board, show that the bacillus of typhoid fever soon dies in water. He concludes that over 90 per cent. die in five days, even when originally present in enormous numbers, and 99 to 100 per cent. in seven days.

It follows therefore that the danger from any source of pollution varies with its distance from the intake, the nearer the pollution the greater the danger. The most dangerous source of pollution is the overflow sewers in the town of Chelmsford. These are so dangerous that it is recognised that unless they are abolished the water could scarcely be made safe. Clause 30 in the Bill is an undertaking not to take any water from the river for the purpose of supply until the flow of such polluting matter has been stopped. When this is done, the crude water will be much better than it is now at certain periods of the year.

The other sources of pollution can be effectively dealt with under powers referred to in the Bill, or even without them, but additional powers are very desirable. Since the people of Chelmsford will have to provide and drink the water, the Corporation of Chelmsford should have the power to stop all dangerous pollutions.

This prevention of pollution may be called the first line of defence. It can never be absolute, therefore other lines of defence are necessary.

The second line will be the collection of the water only when it reaches a certain degree of purity. A chart is appended based on ten weeks daily record of (a) the quality of the water, (b) the turbidity of the water, (c) the daily rainfall and (d) the variation in the 'hardness' of the water.

This chart shows that the rainfall, turbidity, and impurity rise and fall together. An intelligent man by observing the rainfall and the degree of turbidity of the water can tell in a few minutes whether the water is good enough to abstract or not. There will be occasional periods varying from

one to four days, or in very exceptional cases up to seven or eight days, when no water should be abstracted for replenishing the reservoir under present conditions. During 1922, with a rainfall of 23.5 inches (above the average for Chelmsford), there would have been the following intermissions :—

January 15, 16	2 days.	August 12, 13	2 days.
January 18, 19, 20	3 "	September 14, 15	2 "
February 2, 3, 4	3 "	September 19, 20	2 "
April 3, 4, 5	3 "	Sept. 30, Oct. 1, 2	3 "
April 12, 13, 14	3 "	November 1, 2	2 "
April 25, 26	2 "	November 5, 6, 7	3 "
May 1, 2	2 "	December 21, 22	2 "
June 28, 29	2 "	December 27 to 31	5 "
July 4, 5, 6	3 "		
July 14, 15	2 "	Total	46 days

On forty-six days out of a total of 365, the water would have been more impure than is desirable, but in no case would the town have suffered any inconvenience, since the storage at the works and in the town could have kept up a full supply.

He is of opinion, however, that a period of ten days could be tidied over, and a longer period with but comparatively little inconvenience. The Borough Engineer will give details, but briefly the tidying over would be done by (1) reducing takings from stored water at works by 50 per cent. (this could continue for ten days), and (2) by day and night pumping from the deep wells. Thus the full supply could be maintained. After ten days the storage in the town reservoir and pumping from the wells would maintain a nearly full supply for several days more. This, however, is never expected to occur.

If the worst came to the worst, the impure water could be dealt with and rendered perfectly wholesome by the additional lines of defence which will be referred to in a moment.

The third line of defence is the five days storage in the collecting reservoir to admit of equalisation of the quality of the water taken and to give time for further natural purification to take place by sedimentation and destruction of any objectionable bacteria present. This might possibly break down if such a contingency as that just referred to occurred.

The fourth and most important line of defence is the purification of the water by the addition of lime. Professor Frankland very many years ago pointed out the extraordinary purifying effect of lime as used for softening water, and in the witnesses' book on 'Water Supplies' is given a table of daily examinations of a slightly polluted hard water before and after its treatment with lime. Since then, Sir Alex. Houston has published the results of experiments made at certain works of the M.W.B., showing that if a little more lime is used than is needed for softening, the most impure water can be rendered practically sterile and all objectionable bacteria absolutely destroyed.

The Chelmer water is hard, and he proposes to treat it with excess lime, store for twenty-four hours and then filter. Numerous experiments made with the Chelmer water in all its varying conditions shows that the process is easily applicable and is absolutely reliable. The lime not only kills the bacteria, but it removes colour (organic matter) from solution, and reduces the hardness from over 20 degrees Clark to about 8 or 9 degrees. The result is a perfectly wholesome water.

To make absolutely certain of a wholesome water under all conditions, he proposes the installation of an automatic chlorinating apparatus for use in any emergency. It would be a substitute for any line of defence which breaks down.

The final line of defence would be mechanical filtration of the most approved type. This will remove most of the residual bacteria and all suspended matter, and render the water under all conditions perfectly clear and bright.

After this it will be pumped into the service reservoir and mixed with about an equal volume of deep well water before it is supplied to the town.

The appended chart of records taken over a period of three months shows (a) the daily rainfall recorded on the day of observation ; (b) the effect of the rainfall on the turbidity of the water ; and (c) upon the organic matter in the water, and (d) the variations in the removable hardness. Complete chemical and bacteriological analyses were made for weeks, but the results add little to the information given by the chart. In the raw river water the bacteria growing on gelatine in three days varied from a few thousands to 40,000 to 50,000 per cubic centimetre, the *B. coli* was occasionally absent in 1 cubic centimetre, and never present in less than .001 cubic centimetre. In the treated water the total bacteria were few, and the *B. coli* was never found in 100 cubic centimetres."

In examining rivers it is desirable to have gaugings made at different points where there appears to be any difference in the flow. The flow may be markedly decreased if there are any swallow-holes in the river bed, or markedly increased from the presence of large springs. In different seasons where the saturation water level in the pervious subsoil is marked, the springs may become swallow-holes or the swallow-holes may become springs. In the examination of a river which it was proposed to utilise for a public supply, the flow was found to fall off more rapidly than was expected in a dry season, and this the engineers attributed to the fissures admitting water freely from the chalk in wet seasons, and admitting the water from the river into the chalk in dry seasons. The importance of such observations is proved by another experience. A deep well was sunk in a chalk area near a river. During the time of construction the yield of water was copious, and the quality excellent. After coming into use a wet season supervened, the water level in the well rose rapidly, and the water became turbid and impure. The effect was traced to fissures in the adjacent river a little distance above the well, into which much of the river water disappeared.

Other matters relating to river supplies will be dealt with when considering the question of storage, chlorination or other systems of purification. Storage on a large scale has now become such an expensive matter that the provision of large reservoirs must be avoided where equally good or better results may be obtained by the outlay of less capital. In connection with this subject the following abstract from the Local Government report on "Water Undertakings" may be interesting :—

Rivers and Streams. Many of the rivers and streams of England and Wales are utilised as sources of water supply, and from the return it appears that ninety-five local authorities, ten joint authorities, and thirty-four companies obtain water from them.

R. Thames. The river affording the largest quantity is the Thames, which, besides furnishing over 130,000,000 gallons a day to the Metropolitan Water Board, supplies 2,500,000 gallons to the South-West Suburban and West Surrey Companies and 1,720,000 gallons to Oxford, while of its tribu-

taries the Lee furnishes 64,500,000 gallons to the Metropolitan Water Board and the Kennet 3,000,000 gallons to Reading.

R. Severn. The Severn supplies Worcester with 1,473,000 gallons per day, Bridgnorth with 240,000 gallons, and, in summer, Cheltenham with 649,000 gallons daily. Shrewsbury also uses 1,200,000 gallons a day of its water for purposes other than drinking. Of the tributaries of the Severn, the Avon furnishes 715,169 gallons a day to Rugby, the Chelt 991,000 gallons to Cheltenham, and the Wye 1,000,000 gallons to Hereford, while from the head waters of the River Elan, a tributary of the Wye, 72,000,000 gallons a day are available for the supply of Birmingham.

R. Derwent. The River Derwent affords over 11,000,000 gallons a day to the Derwent Valley Water Board.

R. Tees. The River Tees and its tributary the Balder supply 15,000,000 gallons daily to the Tees Valley Water Board. The Tees also supplies Darlington with 2,500,000 gallons daily.

In examining streams where accurate gaugings are not available, it is always desirable to obtain approximate estimates of the relative volumes of the stream and its tributaries. This can often be done by estimating (a) the chlorine in the water of the main stream above the point at which the tributary enters; (b) the amount of chlorine in the tributary water; and (c) the amount in the main stream at such a distance below the point of entry that complete admixture will have taken place. Thus:—

$$\begin{array}{c} a \quad x = \text{proportion of (a)} \\ \quad \diagdown \quad \diagup \\ \quad \quad c \\ \quad \diagup \quad \diagdown \\ b \quad y = \text{proportion of (b)} \end{array}$$

Thus when examining a river receiving the effluent from a sewage farm, $a = 4.3$, $b = 15.0$, $c = 4.75$.

$$\begin{array}{c} 4.3 \quad 10.25 \\ \quad \diagdown \quad \diagup \\ \quad \quad 4.75 \\ \quad \diagup \quad \diagdown \\ 15 \quad .45 \end{array}$$

The proportion of effluent to river water was therefore $.45 : 10.25$, or 4.4 per cent. The actual flow of the effluent was gauged by an engineer and found to be at the rate of 720,000 gallons per twenty-four hours, and later the borough engineer, from a chart reading, gave the flow of the river above the sewage works at the rate of 16,200,000 gallons per twenty-four hours.

We have, therefore,

Actual gauging of flow	16.2 million gallons daily. ¹
Estimated flow from Cl figure	16.4 " "

This test was made to ascertain the accuracy of the method, as the Cl estimations in the waters of the river and its tributaries were being made daily.

¹ It was afterwards found that the gauging was too low since water was escaping through the lock gates.

CHAPTER VI

THE EXAMINATION OF SPRINGS AND WELLS UNDERGROUND WATERS

THE difficulty of defining the underground sources of supply is very great, but it is important to bear in mind that, unless otherwise stated, the definition of a "deep well" in this book is a well deriving water from an underground stratum where this source is covered by an impervious stratum which should effectually cut off all water from the more superficial formation. Springs also may be superficial or deep, but it is often difficult to ascertain the actual source. An analysis of the water or a comparison of its temperature with that of the subsoil waters around usually, however, furnishes a clue: the deeper the source from which the water comes, the higher the temperature. In examining the deep wells in Essex, the temperature was found as a rule to increase with the depth. (*Vide* "Geological Survey, Water Supply of Essex," pp. 69 to 72.)

The L.G.B. report on "Water Undertakings, England and Wales," does not discriminate between the different types of wells for the reasons given in the following quotation from that report which bears on the subject under discussion:—

"Underground Sources. Supplies from underground sources, excluding springs, are mostly obtained by means of wells and boreholes. The particulars of these sources given in the return vary with the details furnished by the undertakers, some of whom describe the wells as 'artesian,' 'bored,' 'deep,' 'tube,' or with 'adits,' 'headings,' 'borings,' etc. The actual number of wells and boreholes from which supplies are obtained is not known, but where the returns furnished by the undertakers contained such details, their depth, situation, and particulars of the water-bearing strata have been given. More complete information on this point will be published later.

For some years the supply of underground waters has been on the increase, and the proportion of underground to surface waters used has been constantly growing. Many important undertakings depend wholly upon wells or boreholes for their supplies. Of the local authorities, Kingston-upon-Hull obtains 12,304,000 gallons per day; Widnes, 5,500,000 gallons; St. Helens, 4,700,000 gallons; Birkenhead, 4,215,356 gallons; Southampton, 3,650,000 gallons, and Warrington, 2,543,075 gallons. The Southport, Birkdale and West Lancashire Water Board obtains 2,658,230 gallons daily from wells, whilst among the companies, Sunderland and South Shields obtains 8,520,000 gallons per day from wells and boreholes; South Essex, 4,804,000 gallons; Great Grimsby, 4,295,000 gallons; and Colne Valley, 3,250,000 gallons. A number of undertakings with other sources also obtain large supplies from wells and boreholes, but the quantities derived from the various sources are not always given. The Metropolitan Water Board obtains 41,066,100 gallons per day from wells and borings; Nottingham, 7,528,059 gallons; Croydon, 4,053,698 gallons; and Wolverhampton, 2,751,000 gallons; and the com-

panies include South Staffordshire with 13,793,498 gallons, and Cambridge University and Town with 1,132,000 gallons.

The information in the return shows that 340 local authorities, thirteen joint authorities, and 142 companies, derive supplies from wells and boreholes.

Springs. The actual number of springs from which supplies are obtained by the various undertakings is not known, but from information in the return it appears that springs are among the sources of supply of 392 local authorities, fourteen joint authorities, and 114 companies. Where the information has been supplied, the geological formations from which the water issues, and the situation of the springs, are stated in the return. Though widely distributed in England and Wales, springs are seldom in great enough volume at sufficient elevation for large gravitation supplies.

Few of the larger undertakings rely for their supplies solely upon springs, but the Borough of Portsmouth Waterworks Company obtain over 8,261,000 gallons, and the Wisbech Waterworks Company supply over 5,138,160 gallons of water per day from springs in chalk, while the local authorities of Lancaster and Bath each depend upon springs yielding about 2,000,000 gallons per day.

Springs, however, furnish the staple supplies of many of the smaller undertakings and make important contributions to the supplies of many of the larger. Among these may be mentioned the Metropolitan Water Board, which obtains 1,712,000 gallons per day from the Chadwell spring in Hertfordshire; the Staffordshire Potteries Waterworks Company obtains 2,120,000 gallons, and the Bristol Waterworks Company, 1,744,000 gallons per day from springs."

It must be remembered that the above information applies only to the year 1914, since when no further report has been issued, and great changes in sources of supply and their yields have taken place.

Where a well or spring is known to derive water from the subsoil around, the sources of pollution must be in the vicinity or not very far away, but the water of a "deep" well or spring may be polluted at a point several miles distant. In fissured formations, whether of chalk, limestone or sandstone, the wells may yield water of unsatisfactory bacteriological quality, and the source be undiscoverable. Then the question of treatment of the supply has seriously to be considered. During recent years many water authorities deriving water from the chalk have adopted treatment, such as chlorination, rather than run the slightest risk of supplying contaminated water.

Only a very small percentage of the shallow wells in this country are either satisfactorily placed or properly constructed, and often a most cursory examination is sufficient to show that pollution is possible. In other cases a more detailed survey is necessary, including the opening of the well and possibly of the ground in the vicinity, to search for drains, cesspools, etc., within the drainage area. The extent of this area depends upon the nature of the subsoil, the depth of the well, the depression of the water level produced by the abstraction of the maximum amount of water required per day, and the direction of flow of the ground water. This applies to all shallow wells, that is, to all wells sunk in a superficial permeable stratum, whatever the depth.

The more porous the subsoil, the larger the drainage area or area of depression produced by the abstraction of water, and *vice versa*. In no case is it safe to regard this area as less than the area of a circle

the radius of which is twenty times the depression of the water level produced by pumping, and in running sand and fissured rocks it may be greater. If, for example, the depression produced is only 1 foot, the drainage area should be taken as extending over a radius of not less than 20 feet from the well as the centre. When the ground water surface has a marked slope, the portion of the drainage area which most requires protection is that where the water level is highest. The surface of the ground water round a well when depressed by pumping has the form of an inverted cone, the sides near the well being steep and gradually rounding off into the nearly horizontal surface of the subsoil water. The velocity of the flow of the water towards the well at any point varies according to the distance of that point from the well, the velocity decreasing more rapidly than the inverse of the square of the distance. For example, if within 3 feet of the well the movement of the water is at the rate of 3 inches per second (probably a higher velocity than ever occurs through any porous stratum), at 30 feet it could not be more than 1 foot in 400 seconds, and at 90 feet the rate would be less than 1 foot in an hour. At a certain distance from the well, therefore, the movement of the water through the soil is slower than the rate of filtration through sand in any artificial system of purification. This, of course, applies only to a subsoil of uniform character.

The depth of the well, or rather of the ground water, should also be considered, since the nearer this approaches the ground surface the greater is the risk of contamination. Where the water level when at its highest is only 2 or 3 feet from the ground surface it will be almost impossible to render the water safe unless the whole of the area of depression is protected. Where the highest point reached by the ground water is 60 or 70 feet from the surface, and the ground is compact, percolation will be so slow that purification is ensured before water from the surface reaches this level. In such a case a very limited protective area is necessary.

As an example of the method of determining the extent of the area to be protected, suppose that in a sandy subsoil, with a ground water level at its highest several feet from the surface, a well is sunk from which 45,000 gallons per day are abstracted and that the maximum depression produced is 9 feet. Each foot of saturated sand yields about $1\frac{1}{2}$ gallons of water. To yield 45,000 gallons, therefore, 30,000 cubic feet of the subsoil would be drained. The volume of a cone being the area of its base multiplied by its height divided by 3, it follows that if the volume be 30,000 cubic feet and the height 9 feet, the area of the base of the cone of depression would be (assuming the sides to be straight) 10,000 square feet, representing a circle with a radius of 57 feet. The cone, however, has not straight but curved sides, yet for all practical purposes the cone is included in the area above given, since beyond that radius the flow of water becomes so slow that efficient filtration must result. A protective area of 20 to 30 yards' radius, kept free from all polluting matter, would probably suffice to render the

water from this well quite safe, but it would undoubtedly be better to have an outer protective zone either uncultivated or simply laid down to pasture.

This so-called cone of depression is often purely imaginary. When actual tests are made by driving tubes round a well, it is in our experience the rule to find that the water level is markedly depressed in one direction and scarcely affected in others. Even in fairly compact sand and gravel beds there are lines of least resistance along which the water flows, and this direction may be very different from that anticipated from the contour of the locality. An excellent example of this is recorded on pp. 61-64, relating to the examination of a spring at Great Baddow, near Chelmsford. For this reason it is always desirable to have a much larger protection area than the calculated area of the cone of depression, and the old Local Government Board usually insisted upon a protection area of 3 to 10 or 11 acres according to the position of the well or spring and the amount of water derived therefrom. The inner zone should be kept free from rabbit runs and from animals of all kinds, but the outer zone may be used as grazing land.

Where the ground is fissured it is impossible to define the protective area, but the direction of the fissures and of the flow of water therein should be determined and particular attention paid to the ground above the well where the fissures come to the surface. If the well is fed by underground drains, the depth and direction of these should be ascertained, and the whole of the area drained should be examined for evidence of the presence of polluting matter. In or near towns, villages, and farmyards, the whole of the water in the subsoil over an extended area may have become polluted. In such cases it is useless to expect to obtain a safe water.

Unfortunately fissures may extend very considerable distances and in entirely unexpected directions. For example, a public water supply was derived from a shallow well with adits in the mountain limestone formation, the water from which suddenly became turbid and contained various low forms of animal and vegetable life such as are usually found in ponds. Fluorescein experiments made in fissures higher up the valley failed to show any connection between these and the well, but inquiry led to the discovery that the onset of the turbidity coincided with the discharge of the water from an artificial lake in an adjoining valley, and an examination of this valley showed the presence of swallow-holes down which the whole of the water from the lake disappeared, only to reappear a few hours later in one of the adits of the well, a mile or so away, in an entirely different valley. The water in its course passed under a hill of considerable elevation.

In examining a water supply from the subsoil the well should be opened out to ascertain how it is covered and constructed, and how the pump pipe or rising main enters; the condition of the sides should be examined to ascertain if there are traces of water entering from near the surface, or whether the rootlets of trees have penetrated

into the wall. The depth of the water from the ground surface, the depth of the water in the well, and the depression caused by pumping may then, if desired, be ascertained. Samples of water taken respectively from near the surface and near the bottom of the well may upon examination give information of importance. If water is observed entering at more than one point, samples from each may be collected and compared. If the pump is defective, the well may be polluted by water used for priming. Ditch water has been poured into the pump cistern for this purpose under the impression that the first few strokes of the pump, when in action, would remove all the impurities. That such is not the case can easily be demonstrated by priming the pump with a solution of permanganate of potassium. It will be found that the whole of the water in the well has become tinted, and it may be days before the colour disappears. (For construction of shallow wells, *vide* p. 68.)

It is often impossible to protect effectually all the drainage area of wells from which large amounts of water are pumped. For example, at a waterworks under our supervision which, from two wells in the chalk, supplies a population of over 20,000, the water yielded during the greater part of the year is exceedingly pure. The works are near a river, and when the river overflows its banks, as it does two or three times every year, the water from the wells deteriorates in quality. The deterioration never occurs until after the land around has become flooded, so that ample notice is given. A deeper well has been sunk at some distance from the river, and the water therefrom is not affected by the floods. Therefore, when flooding occurs, the water from this well has to be used until the old wells are again yielding a pure water. We recommended the installation of treatment plant for use during very rainy seasons, as the authority concerned was unwilling to abandon these works entirely.

In deep wells—that is, wells bored through an impermeable stratum to water-bearing rocks beneath—pollution may occur near the surface, and the upper portion of the well and the surface of the ground require examination, as in the case of a shallow well. If the outcrop of the water-bearing stratum is under the sea, indications of sea-water infiltration must be sought for in the saline constituents of the water, and by comparing the results obtained from the analyses of samples taken when pumping has ceased for a time with those of samples taken after long-continued and heavy pumping. If the outcrop is at no great distance possible sources of pollution should be sought for upon it, and the analytical results will often give a clue to the nature and source of the pollution.

For example, a deep well in the Chalk, from which we examine samples of the water at regular intervals, had shown signs of change, the free ammonia increasing. Careful examination of the water also showed an increase in the sulphates, which led us to suspect gas liquor. A test for sulphites showed that these were also present and a somewhat doubtful reaction for thiocyanates was obtained. Upon going

down one of the wells a distinct odour of gas was observed, all of which pointed to the source of contamination, a gasworks in the immediate neighbourhood.

In another instance, bacteriological examination of the water from a well which was the sole source of supply to a town, showed the presence of sewage or manure-derived bacteria which led to a careful examination of the surroundings of the well. It was found that there was a stable yard in the vicinity, which was littered with manure and not properly drained. The manure and polluted earth were removed and the yard covered with an impervious layer of cement. A month afterwards the objectionable bacteria had disappeared and have not since been found in the water. The well was some hundreds of feet in depth, well lined, but in chalk throughout. Had there been a layer of clay on the top of the chalk, pollution would probably not have occurred.

The mere presence of an impervious stratum, however, must not be accepted as proof that pollution is impossible. A disused well perforating this stratum may have been converted into a soak-away, and we have known several such cases. Also, there may be underground workings of stone or minerals, the adits of which approach the well and may be liable to pollution. All these possibilities must be borne in mind when reporting upon the water supply from any deep well.

In chalk and limestone formations search should be made for swallow-holes within the drainage area of the well. In two Bills before Parliament, water authorities sought to take water from the Chalk in close proximity to swallow-holes (one at the time of inspection was acting as a bourne), but as both undertook to chlorinate the water before delivering to the consumers and to safeguard the swallow-holes as far as possible, the opponents were satisfied. The danger arising from the proximity of the sea or a tidal estuary is so well known as scarcely to need emphasising, but the following two cases are especially interesting. In the first, a well was sunk in the Chalk a few miles from a tidal estuary, adits were driven and a good supply of water obtained. The works were completed, and for a time everything was satisfactory. Then the hardness and chlorine contents began to increase, and many complaints arose. The water was pumped out, and samples collected from every fissure. Upon analysis, tidal water was found to be entering near the end of the adit which had been driven in the direction of the estuary. An attempt was made to plug the fissure, but in a few days the next fissure yielded a brackish water. It was then decided to block the adit with concrete, and this was done and appeared satisfactory for a time, but eventually the tidal water entered again and the well had to be abandoned. In the second case a chalk well with adits near a tidal river yielded a good water for many years, but owing to growth of population, pumping had to be increased until the water level in the chalk around became considerably below the bed of the river, when tidal water gained access and gave rise to serious complaints. Pumping was slowed down, and the well continued to yield a satisfactory water.

Naturally an additional source of supply had to be found to meet the increased demand. It is interesting to note that in neither of these wells, the latter of which was barely half a mile from the river, were there ever any signs of bacterial pollution.

The most careful supervision may fail to prevent a well water becoming fouled. For example, a well which was kept under constant supervision, and the water from which was examined chemically and bacteriologically several times a year, developed a colour suggestive of "picric acid." This increased until a tint was detectable in a large tumbler of the water, and it became a question whether the well would have to be abandoned. Borings in the Chalk around gave an indication that the whole of the colour was coming in one direction, and, in following up this clue, it was discovered that during the war of 1914 to 1918 a small factory had been established for making explosives, and that all the waste liquids had been discharged into sumps in the chalk. The works had been closed some little time and meanwhile the liquids discharged had reached the public water supply. As the colouring matter appeared to be harmless, and its source had been cut off for some time, it seemed reasonable to suppose that the effect would soon pass away. This has proved to be the case. In Kent, the water from wells near Tilmanstone has been markedly affected by the large amount of alkaline water pumped from the colliery. If the water cannot be utilised, it will have to be piped to a stream some miles away.

In small supplies, whether from deep or shallow wells, where the pump is fixed over or near the well, the condition of the paving and ground around and the nature and condition of the arrangement for conveying away the waste water require examination. We have seen a well placed in a recess which was frequently used as a urinal, and the paving was so defective that the polluting matter could readily gain access to the well. The position of all drains, cesspits, cesspools, etc., should be noted, and their condition ascertained. If there is reason to believe that any such are within the drainage area of the well, the supply cannot be considered safe unless these drains, etc., are actually known to be perfect. Some time ago we had occasion to examine the water supply to a large house where typhoid fever and diphtheria had occurred. The water had been examined on several occasions by analysts and pronounced satisfactory. Suspicions were aroused by the very excessive amount of nitrates present, although in every other respect the analytical results were satisfactory. Upon tracing the main drain it was found to terminate in a large cesspool, hitherto unsuspected, within about 10 feet of the well. The cesspool was immediately at the back of a dairy and the well just in front. The cesspool was abolished and the drains diverted. Very soon afterwards the well for the first time failed. This is an instance of the marvellous purifying action of the subsoil, as there was no doubt that the well had been chiefly fed from the cesspool, which had no outlet. The cesspool was acting as a perfect septic tank and the ground around as an aerobic filter. On another occasion we had to report very

unfavourably on a sample of water from a well of some depth supplying a village. The well was within 50 yards of a churchyard, but it was assumed that the water came from the Thanet sands beneath the London clay, which at that point was about 100 feet thick. Upon opening the well the upper 10 feet were found to be constructed of brickwork properly rendered in cement and perfectly sound, but immediately below there were signs of water entering through the interstices between the unsteyned bricks. The well was pumped out and the top of the bore tube exposed. A sample of water taken from the tube at a considerable depth was found to be perfectly satisfactory, and entirely different from the water pumped from the well. There was found to be a considerable amount of alluvium above the clay, and from this the impure water was pouring into the well. At the rectory in the same village the water from the deep well was ascertained to be polluted by pouring paraffin oil on the ground by the side of the suction pipe, as the exact position of the well was not known. In a day or two the paraffin had gained access to the water, and impurities were found to have reached the well from the kitchen drain along the track of the pump pipe.

In waterworks where the large pumps are placed in the well, sufficient care is not always taken to prevent the access of dirt, oil, etc., and the stages may be covered with greasy dust and waste. From "slip" or other causes, water often washes such filth into the well and contaminates the water. We have traced *Bact. coli* found in such waters to the dirt carried down by the men's boots, which dirt becomes detached on descending the ladders and drops into the well. Occasionally, however, objectionable bacteria are found, the presence of which cannot be accounted for with certainty at the time, but which may be explicable later. Some time ago puzzling results were obtained from the examination of the water from a deep well, but the mystery was explained by the detection of some short hairs in a sample of the water. The well was opened and the pump barrel examined, resulting in the discovery of the remains of a rat. It had evidently been drowned in the well, got into the pump, and the rest may be imagined. Possibly such accidents are not uncommon.

When the water in a well becomes turbid after heavy rain, there is obviously some defect which requires prompt attention, since if coarse particulate matter can be washed into the well, pathogenic organisms, if present, could get in also. Some years ago an outbreak of typhoid fever occurred in a small town in Essex. It was limited to persons who obtained water from a tank or well which discharged the water through a small stand-pipe lower down the road. The Medical Officer of Health sent the water to an analyst for examination. It was clear and bright, and gave such good results upon examination that the chemist declared it good. As other cases occurred amongst the users of this water, one of us was consulted, and soon obtained evidence that the water had recently become very turbid after heavy rain. Fortunately heavy rainfall again occurred within a few days,

and a sample of the turbid water was examined. There could be no question of its impurity. The District Council accordingly gave orders for a thorough examination of the source of the water, and it was then found that the drain from the isolation hospital, in which there had been a case of typhoid fever some weeks prior to the outbreak, was defective at a point close to the source of the water. The defect was a break across the top of the drain, and when the drain became nearly full, the contents extruded into the ground around and could be traced to the well.

In tracing such connections and the track of the pump pipe or rising main, and for discovering defects near the upper surface of a well, it is sometimes advisable to use solutions which, either on account of their colour or odour or chemical properties, can be easily identified, even when very largely diluted with water. A strong alkaline solution of fluorescein is very useful for this purpose, as also is paraffin oil, which penetrates rapidly.

If either of these liquids is poured in some quantity on the ground round the top of the well and over the track of the pump pipe, it can easily be seen when it begins to trickle into the well, provided the well is opened out and illuminated. The quicker the advent of the test liquid, the greater is the opportunity for pollution. As the liquid becomes absorbed by the ground, buckets of water should be used to wash it downwards. If the test liquid does not make its appearance in the well until after the lapse of many days, it is possible that the filtration efficiency of the ground would be sufficient to ensure safety. If the well is not opened, water must be drawn from it from time to time and examined. In such a case it is better to use a solution of fluorescein in brine, as the liquid, being denser than the water in the well, tends to sink, and is more quickly diffused through the water in the well. It is an advantage also to keep the water-level depressed as low as possible during the whole period of observation. This facilitates the entrance of impurities, and renders them more easy of detection, since the volume of water in the well is reduced. In examining a well in a garden adjoining a private house, the top of the well was found to be covered with a large stone slab just above the ground surface, and the pump was fixed over the slab, rendering it difficult to open the well. It was upwards of 30 feet deep, and the water-level was some 25 feet below the ground surface. The subsoil was brick earth over sand and gravel. The water upon analysis was found to be very hard, to contain a large amount of nitrates, but very little organic matter, as indicated by the ammonias and oxygen absorbed. As the ground was manured right up to and round the pump, save at one point, and the stone covering was shaken every time the pump was used, the arrangement was not regarded as satisfactory. A solution of fluorescein was poured all around the pump, and followed from time to time by pailfuls of water pumped from the well. In thirty-six hours the tint of the fluorescein was quite evident in the water derived from the pump.

Common salt alone may be used, several pounds being spread over

the ground surface, and water poured over it from time to time. The amount of chlorine in the water prior to the experiment being known, any marked increase will probably be due to percolation of the brine. It must be remembered, however, that the amount of chlorine in shallow wells often varies considerably from time to time and at different depths. Some time ago we examined the water from a shallow well, and found that the chlorine in a sample from the surface was small in amount, whilst in that from the bottom it was very excessive. In a deep well, on one occasion, a difference corresponding to over 300 grains of chloride of sodium per gallon was detected. The water from the borehole was brackish, whereas that from the surface was rainwater, which drained from the paved yard into the well. The inferences to be drawn from variations in the character of a water at different times and at different levels are not always obvious, but an explanation should always be sought.

An interesting instance, whereby the source of the polluting matter entering a well was traced by aid of salt, is given in Dr. Page's report to the Local Government Board on an outbreak of typhoid fever at New Herrington, Durham. The well was sunk in fissured strata, which outcropped some three-quarters of a mile away. Upon this outcrop there was a farm, the sewage from which disappeared through some of these fissures. When the well was examined it was found that the walls were not impervious, and that a small feeder entered on the south side at a distance of 45 feet from the surface, issuing from the brickwork at a rate of 22 gallons per minute. A sample from this feeder upon analysis gave indications of organic impurity, and the chlorine per gallon was 3·4 grains, as compared with 2·2 grains in the well water. In searching for the probable source of this water, Dr. Page visited the farm above mentioned. He says: "The farmhouse and buildings are upon the magnesium limestone, the beds of which dip towards the north. Owing to subsidences caused by the colliery working below, fissures extending to the surface exist in the locality. The drainage of the farm buildings, of a cottage, and of the farmhouse itself (in which latter there is a water-closet) is conveyed to a tank. The overflow from this tank escapes and disappears down an adjoining fissure in the ground. To determine whether a connection existed between this fissure (three-quarters of a mile away from the well) at Herrington Hill farm and the water-bearing strata supplying the 'staple' well, I suggested that common salt should be dissolved and thrown down the fissure. Instructions were given to this effect, and two tons of salt were accordingly thrown down on May 11th. . . . From May 24th a series of daily testings of the relative amounts of chlorine in the water of the reservoir and of the 'feeder' was made. The chlorine in the water of the reservoir varied from 2·3 to 2·8 grains per gallon, that in the 'feeder' from 4 to 6 grains per gallon. On May 29th, with a view to placing beyond doubt whether the increase of chlorine thus shown was due to the salt thrown down the crevice at Herrington Hill, 5 tons of salt were washed down the crevice with a hose-pipe

running for twelve hours, during which time it was estimated that some 100 tons of water were discharged. On the following day the chlorine present in the water of the 'feeder' rose to 15 grains per gallon. The testing was continued for a few days longer, and on June 5th the chlorine reached the maximum amount of 24 grains per gallon. During the next few days it fell again to the former amount. The connection between the two localities was thus conclusively established, and the source of excremental contamination of the water supply demonstrated."

A solution of lithium chloride may be used instead of common salt, inasmuch as salts of this metal are rarely if ever found in ordinary well waters, and when present even in very minute quantities can be detected in the saline residue, left on evaporation of the water, by spectroscopic analysis. The salt is quite harmless, but the expense is prohibitive if a large quantity is to be used. The crude sulphate, however, is comparatively cheap and as useful as the purer salts. In certain cases it has an advantage over fluorescein, since it does not discolour the water and cause alarm among the users. The following is an example of its utility. At a certain waterworks the water supplied to the town suddenly became turbid, and some of the inhabitants affirmed that it had an unpleasant taste and odour. So much alarm was caused that we were asked to investigate, and found that the town was supplied from two deep wells which, though only 15 feet apart, were in no way connected, pumping in one not affecting the level in the other. One well was out of use, and boring was going on from the bottom. To fill in a cavity between two tubes a large quantity of liquid cement had been poured down. Although two tons had been used, the cavity remained. The turbidity, etc., of the water from the other well coincided with the pouring down of this large quantity of cement. A solution of lithium was poured into the opening between the pipes, and samples of water taken from the other well every hour. Within twelve hours the lithium could be easily detected in the well water, proving that communication had been opened up between the two wells and that the disturbance in the one was affecting the other. The test for lithium must be properly applied, otherwise its presence is easily overlooked, the presence of a quantity of other saline matter masking its reaction when the spectroscopic test is applied. The tediousness of this process of identification militates against its use, and renders it more expensive than other methods.

Permanganates are useless, since they are so readily reduced by contact with the organic matter in the soil. Paraffin oil is very cheap and penetrates rapidly, but when it has once got into a well it is exceedingly difficult to remove all traces of it.

Fluorescein is preferable, since it is very soluble in water, has great colorific power, is easily identified, and a trace of it left in the well water is harmless. One gramme dissolved, with the addition of a little alkali, in a litre of water forms an intensely fluorescent solution, and 1 cubic centimetre of this mixed with 50 litres of water exhibits an

unmistakable fluorescence when the water is viewed in a filled litre flask. One part therefore may be said to affect sensibly 50 million parts of water, or in other words 1 grain will impart a visible fluorescence to over 500 gallons of water. This will give an idea of the amount to be used in any particular experiment.

It must be used with care, however, or untoward results may ensue. In a case in which this dye was used, the public water supply was distinctly coloured for three days. In another instance where fluorescein was put into a swallow-hole to ascertain if it had any connection with a well from which water was derived to supply a large town, the water in the town was tinted within seven hours, and naturally caused some alarm. The colouring power is so intense that the greatest possible care has to be exercised to prevent particles of colouring matter getting on to the clothing, boots, hands, face or hair, as it is easily possible for water to become tinted if these precautions are neglected.

Many aniline dyes possess enormous colorific power, but most of them when in a very dilute solution are decolourised by filtration through soil, and others are too expensive or too objectionable in other respects. Fluorescein is only affected in a very slight degree by filtration through earth, sand, or chalk. Very dilute solutions fade slowly when exposed to a bright light, but remain unchanged in the dark. In quantities of 10 lbs. and upwards it could be purchased at about 10s. 6d. per lb., and the relative cost of the different substances used in sufficient quantity to affect say 1,000,000 gallons of water will be

Fluorescein, 6d.	Common salt, 3d.
Ammonium chloride, 3s. 6d.	Lithium sulphate, 30s. to 40s.

For use, 1 lb. of fluorescein should be dissolved by the aid of 1 lb. of caustic soda in 10 gallons or more of water. To detect the colouring matter in samples of water examined, they should be compared with the original water in long cylinders or tubes of colourless glass.

Some waters possess a natural bluish or greenish tint which interferes somewhat with the reaction, and the result should not be regarded as positive unless fluorescence is unmistakable. The following account of an experiment made with fluorescein is taken from a paper contributed to the Association of Water Engineers and published in their *Transactions* for the year 1907 :—

“ In 1905, a series of cases of typhoid fever occurred at the County Asylum near Cambridge, and the Local Government Board instructed Dr. Monckton Copeman to investigate it, and more especially to report with reference to the risk of pollution of underground water supplies by the sewage of the asylum. A detailed description of the geology of the district is given in Dr. Copeman's report. The asylum sewage was disposed of by a crude system of broad irrigation on land which consists of a thin layer of loamy soil covering the chalk. The well supplying the asylum is about 60 feet deep and some 1,200 feet to

the west of the portion of the irrigation area selected for experiment, and about 2,500 feet east from a well at Fulbourn which furnished the chief supply to the city of Cambridge. A hole was dug to the chalk on the irrigation area, and 0.5 kilo of fluorescein, dissolved by the aid of caustic soda, was washed into the chalk, and samples of water from pits and wells around afterwards collected for examination. The results not being conclusive, a further experiment was made, using 5 lbs. of fluorescein. The experiment was started at 11 a.m. on October 18th, and at 3 p.m. the colour appeared in a pit 200 feet N.N.E. ; at 9 p.m. on the 20th, it was found in a pit 700 feet N.N.E., and at 4.30 p.m. on the 21st it was seen in a pit between the sewage plot and the pit in which it was observed the previous day. On October 22nd it was found in the water of the asylum well, and on October 27th in the water of the Fulbourn well. It had therefore taken some 103 hours to travel about 1,200 feet westward, and about nine days to travel 2,500 feet to the eastward. The wide diffusion is an interesting point, as the wells both to the east and the west were affected. At no time previously had these waters come under suspicion, and neither bacteriological nor chemical analyses apparently had ever indicated contamination." Dr. Copeman therefore adds : " It does not, of course, necessarily follow, because the fluorescein should have proved capable of detection at various points, inclusive of the asylum well, at so great a distance in different directions, from the point at which it was introduced, that bacteria, harmful or otherwise, would be equally capable of transmission for so considerable a distance ; but, nevertheless, the results of these experiments are decidedly instructive and important."

The asylum committee were advised to make some arrangement for dealing with their sewage which should remove all risk of the effluent contaminating either of the sources of water, and we were requested to report upon the best method of securing this desirable result. A study of the geology of the district had led us to infer that beyond a certain line the underground water would be travelling in a direction away from the wells, and to prove this a hole was bored on the site, and 2 lbs. of fluorescein, dissolved and suitably diluted, were poured into the bore. It quickly disappeared, but though all the pits, wells, springs, etc., around were watched, no trace of the colouring matter was found. A further experiment on a larger scale was therefore decided upon, and carried out in the following manner : Two boreholes, 30 feet deep, were made at opposite sides of the field selected. They were 110 yards apart, and both yielded water freely. A trench was cut from a point 6 yards north of the south bore to a point 6 yards south of the north bore. This trench was 96 yards long, 1 foot wide, and 6 inches deep. Water was pumped from the south bore at the rate of 25,000 gallons per day, but it filtered through the trench so rapidly that a pump had to be placed in the north bore. When the second pump was started, the whole of the trench could be flooded, and also a shorter trench cut at right angles and communicating with it. Pumping was kept up for three days to saturate the ground, before the fluorescein experiment was

commenced on March 8th. A tub was mounted at each end of the long trench, and in each was placed 1 lb. of the dye. While pumping was continued, the solution was allowed to dribble into the water as it entered the trench. The time occupied in running in the solution was, on an average, four hours. On the 8th 4 lbs. were put in, 4 lbs. on the 9th, 2 lbs. on the 10th, and on the 12th 1 lb. was run direct into the north borehole.

The amount of dye used would have distinctly coloured 150,000,000 gallons of water. Watch was kept at seventeen different points. At no time did any colour appear in the south borehole, but in the north one the water was tinted seven hours after the commencement of the experiment. No trace of colour appeared elsewhere until nine days later, when it showed in the water contained in a chalk pit 300 yards N.N.W.; on March 31st the colour was observed in a well water 1,200 yards further N.N.W.; and on April 7th it was detected in the marsh water near the River Cam, approximately 3,000 yards away, still in the same direction. At no other points was any trace of colour detected. This second experiment, therefore, not only confirmed the first in so far as it showed that water from this locality did not travel towards either of the wells, but it also proved that the coloured water travelled in a definite direction, which, fortunately, was away from the sources of water supply. The depth of colour observed was never greater than that produced by 1 part of the dye in 130 million parts of water, save at the north borehole, where it was much more deeply tinted.

Well waters have on many occasions been found to be impregnated with coal gas which has escaped from defective mains. Such an occurrence is detected by the odour, and a search should be made for the gas main in order to localise the defect. The odour is very persistent, and if all the affected soil cannot be removed the well will probably have to be abandoned. As the soil around gasworks and mains almost invariably becomes saturated with coal gas, the proximity of such works and mains should be avoided as far as possible in selecting a site for a well.

Abyssinian tube wells require that the ground surface around should be protected. Such a well sunk in the middle of a garden, where the subsoil water level is only a few feet from the surface, cannot be expected to yield a pure water. The tube is generally shaken by the action of the pump, and impurities may gain access through the loosened soil round the tube. The pump should be firmly fixed, the ground immediately around rendered impervious, and a proper arrangement made for conveying away the waste water. If there are doubts about the satisfactory character of the surroundings, pour a solution of fluorescein around the tube or where the defects are suspected, and follow this with water as fast as the ground absorbs it. Then collect samples of the well water from time to time during continuous pumping for several hours. The solution is often found to be easily drawn down when pumping is going on.

Where deep-bored wells lined with tubes are used and the tube forms the suction pipe of the pump, there is danger of insuction of

subsoil water if the tube is defective. The action of the pump is to withdraw the atmospheric pressure from within the tube, and the external pressure will force air or water through the most minute defects, through apertures so minute that under ordinary circumstances neither would have passed. When this action has once been set up, the openings are bound to increase in calibre, and insuction becomes still more easy. To detect such insuction, depress the water-level as far as possible by continuous pumping, then pour a solution of fluorescein into a cavity dug round the bore-tube. Continue the pumping and examine in a litre flask or large colourless glass bottle samples of the water raised from time to time. After such continuous pumping, the water should be examined occasionally for some days. In an investigation of this character made by Dr. G. Turner, at the Suffolk Asylum, a solution of chloride of lithium was used, and the insuction proved by the detection spectroscopically of lithium in the water raised by the pump.

Much of what has been said with reference to wells applies equally to springs. Superficial springs are fed by subsoil water, and can only be polluted on the gathering ground of the subsoil water, at points near or above the level of the springs. Attention, therefore, should be chiefly directed to the character of the surroundings of the springs on the upper side.

The following account of the examination of a spring water supply presents so many interesting points that a somewhat detailed description should be of general interest. The works are situated just outside the borough of Chelmsford and supply a population of about 5,000. Water is derived from a spring and from a deep well. During the greater part of the year the spring yields sufficient water to supply the whole population, but in dry seasons when the yield of the spring falls off and the demand for water is increasing, the supply has to be supplemented from the deep well. In order to keep the deep well water in good condition and to be certain that all the pumps, machinery, etc., connected therewith are in good order, the deep well is drawn upon for a few hours each week. Analyses of the spring water were made periodically, and it was found that within twenty-four to thirty-six hours of a heavy rainfall the bacterial content increased largely, and *B. coli* could be detected in from 5 to 20 cubic centimetres of the water. The water, after cessation of the rain, improved rapidly, sometimes regaining its pristine purity in two or three days. It was decided, therefore, to endeavour to ascertain the cause, and observations and experiments extending over six months were necessary to clear up the mystery.

The appended plan and section show the position of the spring, the configuration of the district and the geological details necessary to understand the results of the experiments.

In 1906, house refuse was being tipped in the gravel pit to the south-east, and it was thought that it might possibly affect the quality of the spring water. Gravel is taken out to the water-level and, so far as can be ascertained, the clay bed shown in the section *a-b* has never been

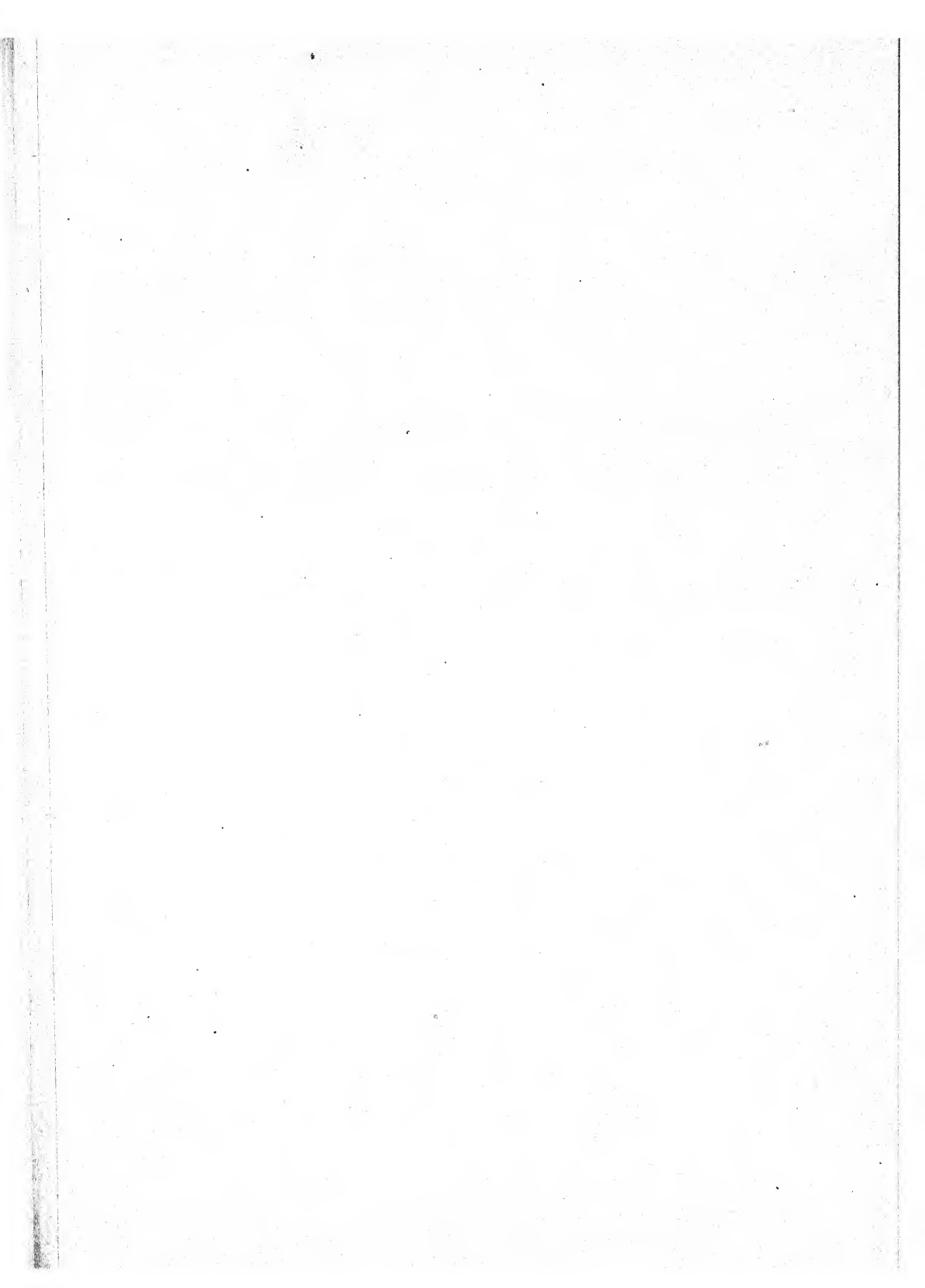
reached. Observations of the water-level in the gravel pits did not indicate any rise or fall or any effect due to the pumping at the water-works. Fluorescein put into the small ponds remained the whole winter. The water appeared to be stagnant. On December 12th, 1906, a hole was made some feet in depth, and 4 lbs. of ammonium chloride added. Samples of spring water were collected daily, and the amount of free ammonia estimated. On December 26th and January 14th a slight excess of ammonia was found in the spring water, otherwise the ammonia remained normal throughout the period of observation (December 12th to January 18th).

There were heavy rains from December 13th to 16th, and melting snow and heavy rains on December 31st, January 1st and 2nd, and in each case the increase of ammonia appeared about fourteen days afterwards. The increase of ammonia was so small that the results were doubtful, but further experiments were rendered unnecessary as tipping of house refuse ceased. In 1910, after discovering the effect of heavy rainfall upon the bacterial content of the water, an attempt was made to ascertain if there was any connection between the gravel pits and the spring by introducing a quantity of fluorescein solution into a hole dug as deep as the influx of the water would allow. The water proved to be stagnant; the colour remained in the water in the hole, it did not appear in the ponds around, nor is there any reason to believe that any ever reached the well. A month was allowed to elapse before any other experiment with this colouring matter was made.

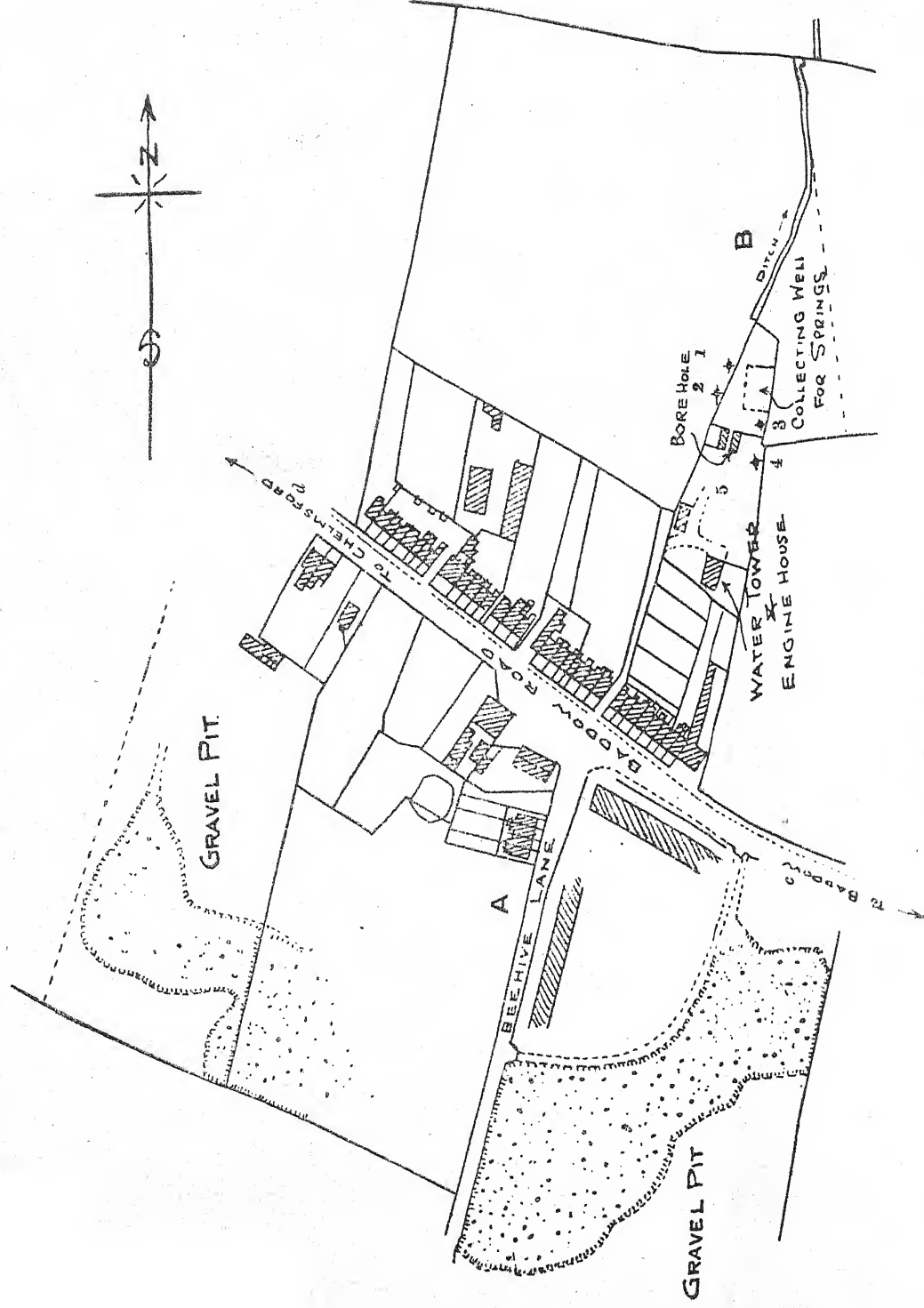
The sewers and drains between the gravel pits and the springs were tested with water and some of them found very defective. The Baddow Road sewer between the points "c" and "d" was treated in two sections, each being filled with a strong fluorescein solution and kept charged with water from an adjacent hydrant. The fluorescein solution made its appearance on the roadside beyond "d" and was visible for days, but no colour appeared in the spring water. The defective drains were similarly tested, at intervals sufficiently long to prevent any confusion arising should the spring water be affected, and besides filling the drains, trenches were cut deeper than the drains and filled with fluorescein solution. The colour remained in the trenches. No trace of colour appeared in the spring water. It began to be obvious that there must be a protecting bed of clay and that any contamination must arise very near the spring.

Trial bores were then made at points marked 1, 2, 3 and 4 on the plan. No. 5 represents the bore of the deep well. No boring was made to the east because the superficial gravel had been removed and lay exposed. The sections obtained were as under :—

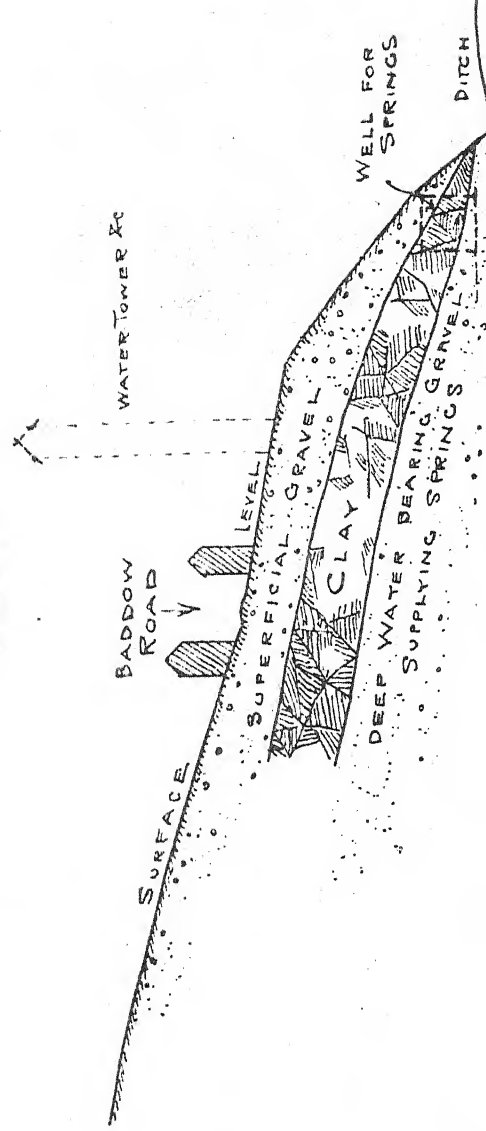
Height in feet of ground surface above the bottom of the reservoir	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
in which spring water rises	6.6	9.6	11.3	16.0	11.0
Surface soil and gravel	3.0	3.6	0.3	8.6	2.0
Clay	2.3	4.6	10.0		
Gravel	2.9	1.0	2.0		
Depth of bore	8.0	9.0	12.3	18.0	12.0



GREAT BADDOW WATERWORKS.



— PLAN. —

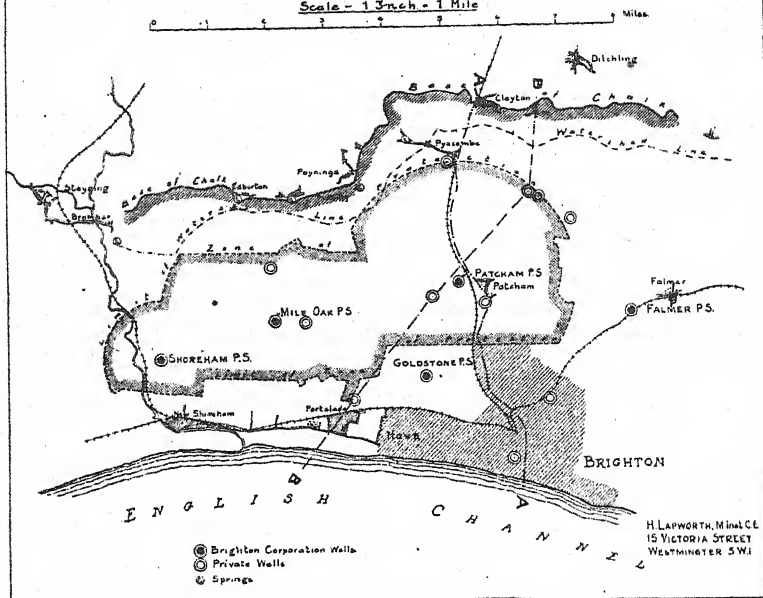


— SECTION A-B. —

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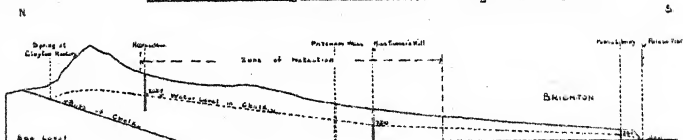
Map of Chalk Gathering Ground.

Scale - 1 Inch = 1 Mile



- BRIGHTON CORPORATION WATER - Session 1924 -

Section A.A along London Road from Clayton to Brighton



Section B.B from Whitelands to Portlads

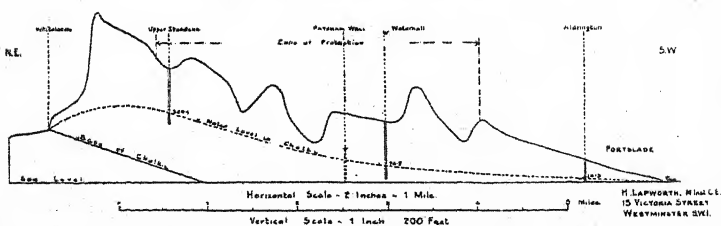


FIG. 4.

In the first instance the borings were suspended as soon as clay was reached, and water only rose in Nos. 1, 2 and 4. Each of the four bores, however, was filled, at suitable intervals, with chloride of ammonium solution and water poured in from time to time to replace the little which escaped. The spring water was examined daily without any increase in the ammonia being detected. About a week was allowed to elapse between each experiment. Ammonia salts having failed, the introduction of fluorescein solution was risked, the only result being that after filling No. 1 boring, the colouring matter was found next day oozing through the top of the bank of the ditch above the level of the outlet of the reservoir. Each boring was now deepened in succession so that the lining pipe was well in the deeper gravel. In bores 3 and 4 the water-level was about the same as in the overflow from the collecting reservoir, but the level remained entirely unaffected by pumping operations, and when the reservoir was kept nearly empty for days the level in the bores did not fall. The colouring matter remained in the tubes, and, when water was poured in, the level fell very slowly and no colouring matter appeared in the spring water. This naturally caused great surprise, but all our endeavours to get colouring matter through failed entirely. No 5 being the borehole of the deep well could not be experimented with. Very different results were obtained when bores 2 and 1 were deepened. In both these the water-level rose and fell with the pumping operations, the effect being more marked in No. 2 than in No. 1. Fluorescein was placed in No. 1 and speedily appeared in the bottom of the ditch, rising up through the gravel for a distance of some yards, but it did not enter the reservoir although the water-level was kept at its lowest for days. The water-level in this bore and in No. 2 never reached the height of that of the overflow of the reservoir. When the reservoir was allowed to overflow, the water-level in these bores remained 12 to 14 inches lower, but when the reservoir was kept nearly empty the water-level in the bores fell about 2 to 3 feet and remained some feet higher than the bottom of the reservoir. Finally, fluorescein was put into bore No. 2, and within twenty-four hours the spring water was tinted, and to such an extent that this source of supply had to be instantly cut off and run to waste, and the deep well utilised for supplying the town. The water remained coloured for three days, but on the fourth day it disappeared and the water was again utilised. While the reservoir was empty and the water running to waste it was carefully examined. The coloured water could be seen "boiling" up through running sand at the north-west corner, and flowing in a large stream under the north-west portion of the wall. All the water which could be seen entering the reservoir was coloured, and all appeared to enter at the north-west corner. In the field to the west there was a ditch receiving manure from a stable. A quantity of fluorescein was put into this and ultimately a little was detected on the surface of the field lower down. It never reached the spring water, not even when heavy rains some months later caused flooding of the ditch in the locality.

The tests made proved—

1. That the spring water entering the reservoir must come in between the bores "5" and "2."

2. That when the water-level was depressed in the reservoir below that in borehole "2," water also entered from the direction of "2."

3. That even during heavy continued pumping, water from "1" did not flow back to the spring but continued its course northward to the outcrop in the bottom of the ditch.

4. That it was necessary to acquire the field to the west to protect the spring.

Control of this field was secured and manure excluded, since when the water has remained unaffected even after periods of heavy rainfall.

The water supplying ascending springs often travels long distances in fissures in the rocks, and is sometimes exceedingly difficult to trace. In Derbyshire and South Wales small streams are often found to disappear down "shaks" or crevices in the limestone, and attempts to discover where the water ultimately emerges, by throwing down salt or flour, generally end in failure. These limestone beds often contain large subterranean caverns which act as reservoirs of water, and the material inserted in the fissures becomes too highly diluted ever to be discovered. Suspended matters doubtless have time to settle. On occasions, however, such underground streams have been traced by aid of soluble salts. The source of the water feeding the springs at Lausen in Switzerland, which caused an outbreak of typhoid fever, was traced by the use of common salt. Flour had been thrown down the suspected fissure on the opposite side of the hill, but failed to make its appearance in the spring water. When salt was employed the chlorine in the water markedly increased.

The following is a rather curious experience, in which the source of contamination of such a spring was traced by the use of common salt after failure with fluorescein.

The spring in question yielded a large quantity of water, and for years had supplied a town of some importance. Chemical analyses, made from time to time, had always given satisfactory results. When a bacteriological examination was made, the *Bacillus coli communis* was found, the water company was apprised of the fact, and samples were examined in our laboratory. At first the *B. coli communis* only was found, but at a later date the *Cl. welchii* was also detected. The spring issued from crevices in the mountain limestone, and, having examined the country for miles round, the conclusion was reached that the pollution must be coming from a certain direction, and most probably from a point near the bend of a river where water might enter through fissures and flow towards the spring. The river water contained both organisms, and the little soil covering the rocks where the suspicious fissures occurred was heavily infected. A strong alkaline solution of fluorescein was allowed to flow for twenty-four hours into the water over the fissure. This was speedily carried away, but no trace of it appeared in the spring water. Next, half a ton of salt was placed in the fissure, and a sample of water was collected every three hours from the

spring. The chlorine in the water increased within twenty-four hours, and speedily fell to the normal after the whole of the salt had been dissolved. There could be no doubt that the organisms found in the spring water came from the river at the point examined, which was more than a quarter of a mile from the spring.

The next example is one of success in tracing the source of pollution of a spring water without the use of chemicals, the proof of the correctness of the views expressed being the results obtained when the report was acted upon.

The affected spring was grossly polluted, the bacterial examination showing the presence of coliform bacteria and *Cl. welchii*, and the chemical analyses clearly indicating contamination with sewage. As there were no houses near, the possibility of sewage pollution was scouted. The spring arose through a fissure in the limestone close to the bank of the River Derwent in Derbyshire. Upon examining the river, it was found that about half a mile above the spring the volume of water in the stream decreased considerably, and was polluted by the effluent from a sewage works about half a mile farther up the valley. This decrease could only be due to some of the water disappearing through a fissure, and from an inspection of the area it appeared probable that there was a connection between this fissure and the spring. The bed of the stream was then concreted, and a very short time afterwards the spring water improved in character and became satisfactory from both the chemical and the bacteriological point of view.

More recently a very large spring supplying a town in South Wales had to be examined, because the water became quite turbid after every rainfall. It was known that swallow-holes abounded in one of the two valleys, just below the junction of which the spring emerged from a fissure. One valley was in the millstone grit and the other in mountain limestone. A stream flowed through each valley, and they met at a point very near the spring. Upon tracing up the millstone grit stream nothing unusual was observed, but upon following up the other stream a portion of the bed was found practically dry. A few yards beyond, water was again found, which received all the sewage from a small mining village. Samples were collected from the stream just above the point at which it disappeared, lower down near its junction with the stream from the millstone grit valley, from the brook flowing through this valley, and from the spring furnishing the water supply to the town lower down. The analyses of these showed that the waters from the two valleys were different in character, and that the spring water was practically identical with that from above the swallow-holes near the mining village, and closely resembled that from lower down the same stream. Obviously, except in periods of flood, all the water in the one valley disappeared at the point indicated into fissures, and a portion of it returned to the stream lower down, the remaining portion coming out at the spring. Further observations proved that this surmise was correct.

Another public supply examined was derived from a subsoil spring

which, in dry weather, yielded water very copiously. The water then gave most satisfactory results both upon chemical and bacteriological analysis, but after heavy rains the adjoining meadows were liable to flooding, and upon such occasions the water became turbid and remained so for days. The chemical analysis then showed some deterioration in the quality of the water and a marked increase in the nitrates. The bacteriological examination revealed the presence of organisms which could only have been derived from sewage or manure. Upon examining the neighbourhood above the spring in the direction from which the subsoil water was travelling, there was found about 300 yards away an area of highly manured market gardens. The whole phenomenon was now explicable. The heavy rains and flooding of the land washed the manurial matter, with its associated microbes and the products of its oxidation (nitrates), into and through the subsoil at a faster rate than purification could be effected, and the polluted water, finding its way along a line of little resistance, passed on without undergoing further change to the spring. Obviously such a source of supply is fraught with danger, a danger the greater on account of the feeling of security likely to be engendered by repeated reports as to the excellent results obtained upon analysis.

The way in which polluted matter, containing bacteria, may in certain circumstances travel a considerable distance even in the subsoil is shown by the following experiment. A trough, 3 feet deep, 1 foot wide, and 24 feet long, was prepared and the bottom covered with small shingle and sand to the depth of 1 or 2 inches. The trough was then filled up with fine sand packed tightly. Into a cavity in the sand at one end water was poured until the whole of the sand was saturated. A tap at the opposite end was then turned so that the water drained slowly away. More water, to which an emulsion of a growth of the *Bacillus prodigiosus* had been added, was poured into the cavity, and samples of the water trickling from the opposite end of the trough were collected every three hours. Within twenty-four hours the *Bacillus prodigiosus* was found in this water. As it was not found in the water taken from the sand at various points, it must have travelled along with the water through the shingle and sand below, which obviously had not become so compact as to act as an efficient filter.

The use of aniline dyes and of common salt or other chemicals in solution is limited, since if poured upon the ground surface they must, sooner or later, be carried down into the ground water, and if used in sufficient quantity be discoverable therein. On the other hand, if not used in sufficient quantity they may become so diluted as to escape detection, and in either case lead to erroneous conclusions, since the *materies morbi* of water-borne diseases is not matter in solution, but organisms in suspension, and the former may reach a water supply whilst the latter are held back by the efficiency of the natural filtration. Many experiments, therefore, have been made to avoid this source of error by using such substances as flour, finely ground mineral colouring matters, etc., suspended in water, but the results generally have been

unsatisfactory. Calced magnesia is found to give the best results, being removable with difficulty, but bacteria may penetrate soil capable of keeping back even so finely divided a substance as this.

The most generally useful organism for experimental purposes is, probably, the *Bacillus prodigiosus*, as it admits of very easy identification, is capable of surviving in the struggle for existence amongst earth bacteria, is seldom found in any water supply and is destitute of any pathogenic property. It must be remembered that it is an undesirable organism to have in a house, and that if premises become infected by it there may be considerable difficulty experienced in getting rid of it. During a recent summer we were consulted by the proprietor of an hotel, who complained that all food stored in his larders became covered with a bright red slimy material in the course of twenty-four to thirty-six hours. The red material was found to consist of masses of *Bacillus prodigiosus*. Bakeries sometimes become infected by it. A little care, therefore, is necessary in its use, and one should hesitate about infecting a public water supply with the organism. This has, however, been done at Turin, where Abba has experimented on the collecting area from which the water in the subsoil is abstracted for supplying the city. Emulsions of the bacillus spread upon the ground over and near the collecting subsoil drains infected the water in from two to seven hours when the ground was kept flooded. When the ground was not artificially irrigated and the cultures were spread on the soil immediately above the collecting drains, which were laid at a depth of 9 feet, a rainfall of $1\frac{1}{2}$ inches in twenty-four hours failed to infect the water in two days, but the organism made its appearance in samples of tap water taken in the city a month afterwards. It had rained on the eighteen previous days. Abba concluded from his experiments that under ordinary circumstances the *Bacillus prodigiosus* would not pass into the water supply, but that heavy and persistent rains would carry it down into the subsoil water. He affirms that this affords valuable indications of the influence of heavy rainfalls in washing any contaminating organisms that may be present on such a gathering ground into the water supply. He found the *Bacillus prodigiosus* a more delicate test for this purpose than the aniline colours. The following is the mode of procedure followed by Abba, Orlandi, and Rondelli at Turin. An agar culture of the bacillus was suspended in 7 or 8 cubic centimetres of sterile water, and a few drops of the emulsion poured into each of a number of Petri dishes, in which 10 cubic centimetres of nutrient gelatine had been placed. After incubation at 22° C. for twenty-four hours, the gelatine was deep red in colour and quite liquefied, but growth was allowed to continue for forty-eight hours, when the mixture was washed into flasks. Trenches were cut in the soil, and the contents of one or more flasks mixed with a considerable volume of water were poured in, or a small embankment of clay was constructed round the experimental area and the dilute emulsion poured on the ground enclosed. Water was then used for keeping the trench or enclosed area flooded for several hours. The water from the source under examination was sampled

every hour, and 100 cubic centimetres of each sample converted into broth by the addition of a sterilised solution of extract of meat, were incubated for twenty-four hours at 20° to 22° C. At the end of this time a little of the turbid broth was poured over the surface of sterile potatoes, and the latter incubated at the above-mentioned temperature. Where the bacillus sought for was present, the surface of

the potato acquired a characteristic red colour. A detailed account of Abba's experiments will be found in the *Zeitschrift für Hygiene und Infektions - Krankheiten*, vol. xxxi. (1899), p. 66, and an abstract by Professor E. J. McWeeney in the *Journal of State Medicine* (January, 1900), p. 47.

Small springs utilised for the supply of water to but one or a few houses are often found totally unprotected, and many so-called springs are really subsoil drains, sometimes draining highly manured land. Such springs cannot be considered satisfactory sources of supply.

It is regrettable that sanitary authorities do not possess the power to make bye-laws with reference to the protection of springs and wells, but if they would insist upon springs being properly protected, and wells being properly constructed before granting water certificates to new houses, some improvement would gradually be effected.

The following is a copy of a leaflet originally drawn up for the use of a rural district council :—

“ THE CONSTRUCTION OF SHALLOW WELLS

“ In the large majority of cases where shallow wells yield polluted water it is due to defects in the construction of the wells. The following

CONSTRUCTION OF SHALLOW WELLS

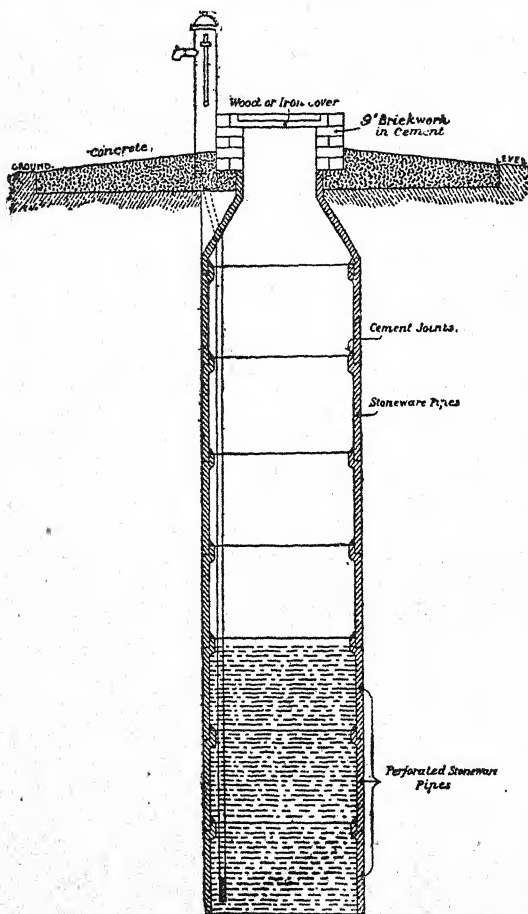


FIG. 2.

suggestions are submitted for the construction of such wells. The water, which enters a well at a depth of 6 to 12 feet, depending upon the porosity of the soil, is usually efficiently filtered and purified. Water entering at a less depth is nearly always liable to be imperfectly purified and unsatisfactory in quality. The nearer the ground surface at which water can enter, the greater the danger of pollution.

"It follows therefore that the upper 6 to 12 feet of the well should be water-tight, and that the top should be so finished off that no surface water can possibly gain access. It is also very desirable that the top of the well should be brought up 6 to 12 inches above the ground surface and covered with a proper flag stone or wood or iron cover.

"Plans showing two of the simplest methods of well construction are appended.

"As no new house can be occupied without a certificate from the sanitary authority to the effect that the house has a sufficient supply of wholesome water, it is important that builders and others should pay particular attention to the above suggestions, and so avoid the risk of a certificate being refused."

CONSTRUCTION OF SHALLOW WELLS

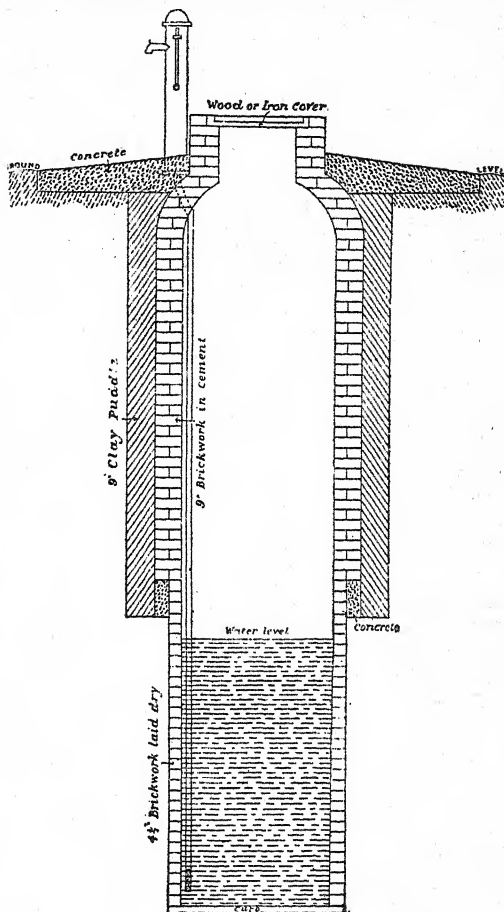


FIG. 3.

NOTE

Bye-laws for the Protection of Water Supplies

Parliament has empowered many water authorities to make bye-laws for preventing the pollution of rivers, springs and reservoirs, and for protecting from pollution areas of land around wells and adits. In populous localities, or in localities likely to become populous, it is often desirable to obtain such powers. Where wells are sunk throughout in pervious subsoil, more especially in chalk areas, some protection may

be afforded if the water authority can control the drains, closets, cess-pools, etc., on land around the well and adits. In the Margate Act, 1902, this power was given to extend over an area of 1,500 yards from any well or adit, and Brighton has obtained such powers over an area with a radius of two miles or thereabouts around each well and adit. As this became a precedent a very brief description of this waterworks and area is appended. The position of the wells to be protected and the area of ground to be purchased or controlled by bye-laws are shown on the plans opposite p. 63. These plans are also interesting since they show the contour of the chalk, the area of this formation and the water level in various wells, which are the points chiefly taken into consideration in deciding upon the area required for protection purposes. In recent years, the Downs behind Brighton have been built upon, estates are being laid out, and the chalk being practically bare in many places it was obvious that if steps were not immediately taken, the chalk would be seriously polluted by sewage, and sooner or later the polluting matter would get into the fissures and reach the wells or adits and endanger the purity of the water upon which the prosperity of the town so greatly depends. The plans are self-explanatory and render any further description unnecessary.

It may be added that whilst Parliament gave the Brighton Corporation power to make bye-laws, these bye-laws can only be enforced after receiving the sanction of the Minister of Health, and over areas approved by him.

CHAPTER VII

EXAMINATION OF WATERWORKS, RESERVOIRS, FILTERS AND PURIFYING PLANTS, MAINS, ETC.

IN most cases where a water is found unsatisfactory, the source of the water has been examined, and no explanation discovered, attention has to be directed to the waterworks, or the place where the water is pumped, filtered, or otherwise purified, softened or stored for service purposes. It may be necessary to examine the trunk or branch mains, and occasionally also the house service. The investigation will depend upon the nature of the contamination, of the changes in the character of the water and the complaints which may have been made. These complaints may be classed as follows: (1) turbidity as the water is drawn, or after standing; (2) living animals or plants being found in the water as drawn from the tap; (3) discoloration, with or without turbidity; (4) odour and taste; (5) some outbreak of disease which has led to the water being suspected as the cause.

1. **Turbidity.** Complaints of turbidity are very common, and in the case of recently sunk wells this may be due to the disturbance of the soil and soon pass away, but in the majority of cases the deposition of ferric oxide or oxycarbonate is the cause. This deposition may be due to the water at the source containing iron in solution. Where the amount of iron present approximates to 0.1 parts per 100,000, the water soon becomes opalescent when exposed to air. The oxide in the mains will deposit and be carried into the service pipes from time to time. Manganese may also be present, and similarly give rise to deposit and turbidity. Such waters require treatment by aeration and filtration, or filtration through polarite, or precipitation by means of lime if the waters contain much free carbonic acid gas. The original water, however, may be free from iron, in which case the iron must have been taken up from the mains. This may be due to the use of imperfectly coated mains, or to defects in the coating, associated with the use of a water containing little silicate or carbonate, especially if rich in carbonic acid or containing chloride of magnesium or calcium. This action is the chief cause of trouble to water engineers who have charge of soft, moorland supplies which may have to pass through many miles of iron mains. The action of various low forms of vegetable life upon mains will be referred to later. There are also waters which appear to have no action upon iron in the cold, but which act upon such pipes after being heated. In such cases it is better to substitute block tin or copper pipes. Galvanised iron pipes serve for a time, but water which acts on iron also acts on zinc, and as soon as the zinc has been removed action commences on the iron.

Turbidity of a curious character is caused by heating water containing much zinc in solution. As the temperature nears boiling point the water acquires a milky appearance, and an iridescent film forms on the surface leading to complaint that a film of oil appears when the water is boiled. A milky appearance also occurs when water which is well aerated is drawn quickly from a tap, and it is not uncommon to receive complaints that the water is "chalky." Even when it is pointed out that such a water clears from below upwards and shows no sign of deposit when clear, consumers will not always believe that the effect is simply due to bubbles of air released by the diminished pressure.

Generally speaking, sporadic outbreaks of turbidity are due to inefficient flushing of the mains, and it is often necessary to impress upon a water authority the desirability of more frequent flushing. Such flushings are especially needed at "dead ends," where deposits are likely to accumulate. These "dead ends" cannot always be avoided, but wherever possible they should be connected to some other portion of the main to ensure continuous circulation of water. The following investigations regarding complaints of turbidity are interesting, since both would have resulted in litigation had not the parties concerned been wisely advised.

In the area of a water authority deriving water from the chalk near an estuary, the mains had been extended at the request of an owner for the supply of a limited number of houses. There were complaints of an oily scum forming on the water when boiled, and one user submitted a sample to an analyst. The analyst condemned it as polluted because it contained nitrites and a little ammonia which he said pointed to sewage pollution. Upon inquiry it was found that all the complaints arose at houses with long lengths of service pipes of galvanised iron, and that the condemned water contained zinc, the presence of which was overlooked by the analyst. The oily film produced on boiling was due to the iridescence of the carbonate of zinc thrown out of solution by heating, and the nitrites and ammonia were due to the reducing action of the zinc on the nitrates present in the water. The result of the investigation was that the water company adopted regulations insisting upon the use of lead for service pipes, and, after a public inquiry, those regulations were sanctioned.

In another instance a water authority extended the mains in several directions, and after the connections had been made complaints were received from persons along the route of the extended mains about the turbidity of the water, but especially along the "T" main. A somewhat lengthy investigation was made, which showed that the water from the old mains was always bright, but that all samples taken from the three recent extensions were more or less turbid, either when drawn or within a few minutes afterwards. The worst samples were always from the "T" main, which was 2,600 yards long and had no house connection for a distance of 2,000 yards. The water might be merely tinted brown, and be fairly clear when drawn, but upon exposure to the air it speedily began to deposit oxide of iron, and in a few hours

there would be a marked brick-red sediment at the bottom of the containing vessel. The "T" branch pipe was not coated with the ordinary black varnish, but with some kind of paint, and the other branches complained of were coated in the usual manner. Samples of these latter were obtained, and, having plugged one end, they were allowed to stand full of water for twenty-four hours. In no case did the water take up more than the most minute trace of iron, and the samples remained perfectly bright afterwards. When, however, patches of the varnish inside were scraped off, the water dissolved marked quantities of iron, and became turbid afterwards when exposed to air. There can be no doubt that in these branch mains the pipes were not thoroughly coated, hence the action of the water.

The analysis of this water showed it to contain in parts per 100,000 :

Calcium carbonate	5.0
Calcium sulphate	2.7
Magnesium sulphate	1.0
Magnesium chloride	0.9
Sodium chloride	2.4
Sodium nitrate	3.9
Silica, etc.	0.6
Total	16.5

The amount of carbonate present is barely sufficient to prevent the action upon metals, especially in the presence of an excess of carbonic acid, and it was found that the water acted markedly upon galvanised iron pipes. There was little doubt that this acid was dissolving iron from parts of the main imperfectly coated, and we attributed the action complained of to the faulty coating of the recently-laid mains.

As the "T" branch belonged to a private company, the water authority was not responsible.

In both the above instances investigations into the character of the water mains, service pipes, etc., were found to be absolutely necessary to supplement the information gained by the analyses of the waters, in order to enable a correct conclusion to be drawn.

Another cause of turbidity is due to the water pipes becoming conveyors of electric current. In many towns corrosion of mains and meters has been traced to stray currents from tramway lines. This effect of electric currents, including galvanic action, must, therefore, always be borne in mind when investigating causes of turbidity which cannot otherwise be explained. This matter became so important that Regulations for Controlling the Earthing of Electrical Installations to Metal Water Pipes and Water Mains were drawn up by The Institution of Civil Engineers.¹

2. Living Animals and Plants found in Water. The presence of low forms of animal and vegetable life is an exceedingly common occurrence

¹ Copies obtainable from William Clowes & Sons Ltd., 94 Jermyn Street, London, S.W.1.

in small supplies drawn from shallow wells, especially if these are open and the water drawn by bucket. In water from imperfectly protected springs they are also frequently found. Public supplies rarely contain visible particulate matter, but occasionally the mains become infected. In two cases of such infection which came under our observation within a few weeks of each other, the living organism was an *anguillula*. In the first case, consumers of the water from a large public supply complained of the presence of minute worm-like bodies in the water as drawn from the taps. There were no ball hydrants on the mains, and careful examination of the water as drawn from the wells failed to discover visible living organisms of any kind. We then directed that the service reservoir should be examined, and when this was done numerous specimens of the worm were found on the bottom. The tank was thoroughly cleaned and the mains well flushed. No *anguillulae* have since been seen. In the second case, the drinking water on a yacht was found to contain "worms," which were submitted to us for identification and found to be *anguillulae*. When the water tank was opened and examined, they were found therein in abundance. The tanks were cleaned and chlorinated and freed from the pests. Possibly birds were responsible in the first case for conveying the eggs to the service reservoir, although it was well covered to exclude animals and light, or the eggs may have been carried in with dust by the wind. In the yacht's tank they must have been introduced when the tank was being filled, although those responsible denied the probability.

The extent to which a whole water supply may be affected by ball hydrants is well illustrated by the experience of Edinburgh in the winter of 1905-6, as recorded by Dr. Williamson, the late Chief Sanitary Inspector and Medical Officer of Health.

Early in December, 1905, complaints were received that the water supply to the city contained water-fleas, and Dr. Williamson obtained specimens of these and found that they were not water-fleas, but insects of an entirely different character, usually known as "spring-tails," on account of the peculiar manner in which they jump about. Several different species were ultimately recognised by the authorities consulted. They are not aquatic, but breed in damp dark places, yet they were found in some of the water cisterns examined, and it was ultimately discovered that the insects were breeding in the boxes of the ball hydrants. In about 30 per cent. of the ball hydrants inspected the insects were found in larger or smaller numbers. In not a single instance were they found in the valve hydrants. Some of the ball-hydrant boxes were found half full of liquid filth, but in such cases no insects were present. The way in which the insects and other objectionable matters were conveyed from the hydrant boxes to the house water supplies was ascertained in the following manner, as described in Dr. Williamson's report:—

"It still remained necessary, in order to complete the inquiry, to establish beyond all doubt the fact that insects found present in the ball hydrant can, with the greatest readiness, be transferred to cisterns

in the immediate vicinity, and, in order to determine this, experiments were conducted.

"A hydrant box was selected, situated in Cowgate, and containing a considerable number of insects. The majority of these were found present on the under-surface of the metal cover placed over the ball valve. This cover was left *in situ*, and the cisterns in the tenements in the immediate vicinity were emptied and cleansed. Gauze bags were affixed to each feeding pipe supplying these, and with the assistance of a water officer the pressure in the street main pipe was reduced. The moment this was accomplished the ball valve in the hydrant box was opened and the contents of the box were rapidly transferred to the main water pipe; the supply to the tenements was immediately turned on and the cisterns filled. On this being completed, the gauze traps were removed, and in five out of eight of these the insects were found present. This formed an absolutely convincing proof of the ease with which insects existing within a hydrant box, as well as all liquid material, may gain access to the main water supply, and from thence to the cisterns in the vicinity, whenever the pressure is lowered; and it further proves that it does so readily, despite the precaution of placing a metal cover over the ball, in conformity with the system at present generally in use. This cover, in the experiment just recorded, formed no impediment to the immediate disappearance of the box contents.

"The last experiment made was with the view of determining the facility with which any liquid contents of a hydrant box could gain access to the water supply. For this purpose a box was filled with clean water, and the pressure in the main was lowered by the method commonly adopted. Within a period of three seconds the whole contents of the box were sucked into the main water pipe. This experiment was important in order to demonstrate with precision the destination of the objectionable liquid which was found present in several hydrant boxes in the city, and which must of necessity collect there from time to time."

This Edinburgh experience emphasises the importance of including the mains and everything connected therewith in all investigations bearing upon the contamination of a public water supply.

Interesting finds are often made when old water mains are examined. Some years ago old mains removed at Poplar were found to be encrusted with fresh-water molluscs, and more recently a 36-inch main, taken up at Hampton-on-Thames, was opened and its bore was found to be reduced to 9 inches by a mass of fresh-water mussels. It is said that 90 tons of mussels were removed from a quarter of a mile of the main. No less than eleven species were found in the Poplar mains, but Locard discovered many more species in the water mains of Paris.

Occasionally it is necessary to cut out short lengths of main to ascertain its condition or the presence of any growth. Such growths are likely to occur where moorland water, inadequately filtered, is turned into the mains. Low forms of vegetable or animal life capable of growing in the dark and of attaching themselves to the surface of the pipes may increase to such an extent as to block the smaller mains.

Recently, in an English town, when a length of main was cut out, it was found to be encrusted with a moss-like growth of *Polyzoa Plumatella*, a fresh-water polyp referred to in a later section. Further investigation showed that it occurred in the newer and well-coated pipes, and not in those which were old and very rusty. The pipe on which it was first observed had been down only two and a half years. The growth caused considerable trouble, particularly in the warm weather, then breaking away and blocking water meters, ball cocks, etc. It also made its appearance in the water drawn from the mains, especially when the water had been allowed to flow full bore into a bath. The water was derived from moorlands and was not sufficiently filtered. More efficient filtration has since been introduced, and probably the growth has now disappeared. It is interesting to note, however, that the growth gave rise to no complaint of taste or odour.

Another "worm" infection of water in the mains through ball hydrants is referred to and illustrated in Plate XXXVI, and Mr. Wood, F.I.C., of the Somerset County Council laboratory, sent us a specimen of water from the main of a town supplied with unfiltered moorland water which contained a worm about 7 cm. long and 1 mm. diameter, looking exactly like a fine looped rusty wire. In the Cambridge Natural History Series it is illustrated and its life-history given—a most interesting one. It is called the Gordian worm (*Gordius Iolosanus*). It frequents the small plants growing at the edge of pools, and streams.

Many other low forms of vegetable and animal life will be referred to in the section on the microscopic examination of visible particulate matter found in water supplies. Where water is taken from moorlands or rivers without filtration, or with an imperfect system of filtration, any form of life small enough to get into the mains may be discovered. Ova and very young forms may pass through strainers and develop in the mains. Even dead mice, water-rats, frogs and eels have been discovered blocking small branch mains and service pipes.

3. Discoloration. Usually complaints of colour are subordinate to complaints of turbidity, but occasionally complaints of colour alone are received. Often this is due to the influx of peaty waters in moorland supplies. On more than one occasion the colour produced by fluorescein has caused alarm, this chemical having been used for tracing sources of pollution in quantities more than sufficient for that purpose. The relation of colour to organic impurity will be dealt with in a later section. All natural waters possess some colour, and it is only when this becomes obvious in the carafe or in the bath that complaints arise.

4. Odour and Taste. Complaints of odours are very common, and are often very difficult to explain, since by the time a sample of the water reaches the laboratory the odour may have disappeared. In many cases the odour appears to be due to the action of the water on the pipes—the metal or the coating—but sometimes it is due to sulphuretted hydrogen formed in the subsoil, especially where this

contains both organic matter and iron pyrites. Almost any kind of water, when allowed to stand in contact with iron in the absence of air, has an appreciable and disagreeable odour when poured out quickly into a tumbler. The odour is usually suggestive of phosphoretted hydrogen or acetylene, and passes off very quickly when the water is exposed to air.

A most interesting case of this kind which caused a great deal of anxiety to the water authority concerned can be recorded. The company had recently extended their mains some three or four miles, and foreign pipes had been used. Many complaints of odour in the water soon arose, and legal proceedings were threatened. We investigated the matter thoroughly and found that (1) the complaints only arose towards the far end of the recently laid mains; (2) many users of the water did not detect any odour (these were cottagers who rarely drew water in any quantity); (3) those who did complain lived in large houses and noticed the smell when the bath was being filled, and the more rapidly the water flowed, the worse was the odour. At a small laundry the occupiers said that when the washtubs were being filled the women had to leave the room on account of the offensive character of the odour. All agreed that the odour rapidly passed away. There seemed very little doubt that the odour was due to the action of the water upon the iron pipes. The great expense which would be necessitated by taking up the mains caused an investigation to be undertaken to ascertain if the action could be prevented. It was argued that, if the presence of air caused the offensive compound to be destroyed so quickly, aeration of the water would cause its destruction at the instant of formation. Aeration by cascading was tried, and was so successful that the engineer devised a method of supercharging the water with air in the mains. This was intended not merely to increase the oxygen in the water, but also to obviate cascading and exposure, which did not improve the bacteriological quality of the water. The process has proved eminently successful. No complaints of odour have since been received, but there are still consumers who think that the cure has been effected by putting chalk into the water, since when first drawn the fine bubbles of air given off impart to it a chalky appearance.

Since the introduction of chlorination complaints occur from time to time of odours obviously due to the chlorine. These have in certain cases been traced to the action of this element upon some coal-tar product which has gained access to the crude water after a heavy rainfall on recently tarred roads. No road which drains into a stream, the water from which is used as a public supply, should be tar coated, especially if the water is to be purified by means of chlorine, since the chlorinated phenols have an intense, unpleasant, and persistent odour and taste. When chlorine was first used an excess was often employed, and complaints of odour and taste were numerous. At the present time complaints are very rare. Where they do occur, inquiries should be made as to the amount of chlorine used, the amount found in the water in the mains, etc., and if an excess is found, less chlorine must be used.

If this is impossible on account of the amount required to effect sterilisation, then some means must be adopted to remove the excess chlorine. Samples of water about which complaints have been received are usually quite odourless by the time they reach the laboratory for examination, and it is generally found that the complaints are local, affecting one house or group of houses, and not adjacent houses deriving water from the same mains. The effect of prejudice is well illustrated by the following incident. We had supervised an installation for the chlorine treatment of a public water supply, and although great secrecy was observed the fact soon became known, and in a few days a claim was made against the company by a manufacturer, who affirmed that the chlorinated water supplied had caused him a serious loss. When the solicitors investigated the case, the claim was found to refer to a certain day when a large amount of water was used for a certain process. It was then discovered that on the date referred to not only had the water not been chlorinated, but the chlorine compound to be used had not reached the waterworks. Needless to say, the claim was not pursued. (*Vide* Chapter on Chlorination.)

After the laying of new mains, the water passing through has usually a tarry odour and taste, which passes off in a few days or weeks, but in one instance, we investigated complaints of discoloration and tarry odours twelve months after the laying of the mains. The mains were of foreign manufacture. We had to assure the consumers that the water was not harmful and that doubtless the effect on the pipes would pass off, as it was already decreasing. Fortunately the prediction proved to be true, but the effect must have continued for some eighteen months. Complaints of taste alone are rare, but recently we have had to investigate two such cases. The first was a complaint made by a consumer who had installed a Permutit water-softening plant. A sample of the water, when examined, was found to contain a considerable quantity of calcium chloride, to which the taste was attributable. The whole fault was due to the manner in which the Permutit was revived, the instructions given by the makers not having been followed. When they were carried out the water had no taste. In the second case a sample of water was received, and the reason given for desiring the analysis was: "This water has an unpleasant taste, and tea made with the water turns black. The well was cleaned out two months ago, but no improvement has resulted. Well 41 feet deep and contains 6 feet of water." The water gave, upon analysis, the following extraordinary results:—

	Parts per 100,000.
Free carbonic acid	3.7
Non-volatile acid equivalent to	0.8 c.c. $\frac{N}{10}$ acid.
Chlorine in chlorides	10.8
Nitrogen in nitrates	3.5
Hardness	22 (20 permanent).
Silica as silicate	4.4
Total silica	5.9

	Parts per 100,000.
Free ammonia . . .	0.0048
Albuminoid ammonia . . .	0.0064
Oxygen absorbed . . .	0.080
The Bacillus coli found in . . .	1 c.c.

The water which was derived from the Greensand did not contain any iron, but when it was boiled in a tinned-iron or iron kettle, it took up sufficient iron to exert a marked effect on the tea infusion.

On other occasions complaints of taste have been due to the presence of iron, or an excess of salts of sodium, generally the chloride or sulphate. In Essex highly sulphated and saline waters abound.

Some years ago the Local Government Board withheld sanction to the completion of a deep well because the water obtained contained 107 parts of sodium chloride per 100,000. When it was pointed out that water containing more chloride was in use in several parts of the county, and that the public supply on Foulness Island contained 141 parts of salt and had been used for many years both for domestic and farm purposes without any objection having been made to it, the sanction required was granted. The salt is perceptible to the taste, but the inhabitants, who at first protested, now consider it an extremely good water. As the result of inquiries made, the opinion was expressed that anything up to 100 grains of salt per gallon was certainly harmless.

The sulphated waters are objected to not so much on account of their flavour as upon their tendency to cause diarrhoea, especially amongst children. A well water which contained about 130 grains of magnesium, sodium and calcium sulphates gave rise to so many complaints of diarrhoea amongst those using it that we had to recommend that its use by the public should be prohibited. On the marshland, where the cottagers have to use pond water, which is not only sulphated but contains much vegetable matter, complaints only arise when there is a change of tenants. Until the newcomers get used to the water they suffer more or less from diarrhoea.

5. Complaints of Illness being due to the Water. Where there is an outbreak of illness affecting a number of persons spread over the whole area served from one source of water, the problem of deciding whether it is due to the supply or not is often most difficult. In such an investigation, where a few sporadic cases have occurred and where water is laid on, it is best to commence by comparing the analyses of samples of water taken directly from the main, from the taps supplying water for drinking purposes to the households affected, and adjacent houses. In one case, on making such analyses in connection with the water supply of a large public institution where anomalous cases of illness had occurred, it was found that the supply from the main was quite satisfactory, whilst that from the tap was impure. Upon examination of the water cistern the remains of a decomposing bird were found therein. The contamination of water in house cisterns is so common an occurrence that no sample of water

which has passed through a cistern should be taken as a sample of a public water supply. Some years ago a series of cases of typhoid fever occurred in a group of cottages near a sewage works and house refuse tip. The cottages swarmed with flies, and the small cisterns in the sculleries each contained thousands. It is possible that the flies carried the specific infection from the sewage sludge and house refuse to the water supply. The water taken at the cottages was bad both chemically and bacteriologically, whilst that taken from the street main was excellent in all respects.

In another case a patient residing in a large house was found to be suffering from enteric fever, and a sample of the water supply was reported to be bacteriologically impure. Legal action was threatened, and we were requested to investigate, since we had always reported favourably upon the public supply. The lady of the house was interviewed, and as she had herself taken the sample of water which had been examined, she offered to take the bottle presented and fill it at the same tap, which was the one from which all the water for drinking purposes was drawn. The tap was a large one, and without running any to waste she filled the bottle. On being asked if she had seen to the cleanliness of the tap she was offended, but when persuaded she put her finger into the tap and brought away with it about a small thimbleful of a slimy substance resembling dirty sago pudding. She declared that the sight made her ill, and fully recognised that water taken from such a tap could not be pure. After the tap had been properly cleaned, the water taken therefrom was free from all objectionable bacteria. It should be added that the water did not pass through any cistern, and that the tap was on the scullery sink.

Apart from any complaint or suspicion of illness, if a sample of water is found to be impure when examined chemically and bacteriologically, investigation becomes necessary. If the supply is only to one or a few houses, the local sanitary inspectors can generally be trusted to make the required investigation as to the structure of the well or details of the source, and to examine any cistern or house fittings. In cases of illness where a number of houses are supplied from one source the question arises whether there are many or few of the houses affected, or if there is any grouping of cases which may throw some light on the source of infection. Where cases are widespread, skilled investigation is necessary, commencing with the sources of the water and following the water up to the points at which it reaches the consumers. The sources being satisfactory, the next point is the examination of the service reservoirs.

Service reservoirs may be improperly constructed or inadequately protected. Where they are excavated in the ground the upper edges may not be raised above the ground level, hence frogs and other animals get in, and heavy rainfalls wash in objectionable matter. In one such instance a serious and widespread outbreak of diarrhoea occurred among the users of water which passed through the service tank. There had been an exceptionally heavy fall of rain a few days before the outbreak

occurred, and when the tank was examined a good deal of earth and sand was found to have been washed in from the adjacent road, and from a patch of garden ground adjoining one side of the reservoir. There were also many worms and other objectionable forms of animal life at the bottom of the tank. When the reservoir was excluded for cleaning and repairs, the epidemic came to an abrupt termination. In another case, consumers complained that the tap water frequently contained small worms and other visible organisms. The service tank was surrounded by a narrow footpath, and beyond this the ground was raised in the form of an embankment, the slope being covered with grass. Here again the reservoir, when examined, was found to contain soil, worms, etc., which had undoubtedly been washed in from the ground around. The raising of the edges of the tank well above the ground level would prevent pollution of this character.

Such reservoirs should be covered so as to prevent the access of light, rain, bird droppings, animals, larvæ, dust, etc. If light gains access there is danger of algoid growth causing trouble, and if uncovered all kinds of objectionable matters may gain access. The overflow from such a tank should be traced. On one occasion an overflow pipe was found very improperly trapped and connected with a public sewer. Even with a proper trap this is an objectionable arrangement, as water may overflow so rarely that the evaporation of the water in the trap would cause it to become unsealed, and therefore useless.

Where the reservoir is underground the covers and ventilators should be examined to see that they admit the minimum amount of dust, and that the covers do not let in dirt, spiders, wood-lice, etc., as is too often the case.

An engineer who examined a service reservoir at our suggestion found therein the macerated body of a young rabbit. The only possible way in which it could have gained access was through the curved ventilators. The ends of these should always be covered with wire cages.

After the service reservoirs have been examined, inquiries should be made about the mains and their condition, the use of ball hydrants, etc.

Impurities may enter water mains through defective joints, cracks, and perforations, and also at ball hydrants and air valves. The condition of the water mains should, as far as possible, be ascertained, especially if they are old, the ground being opened out at selected places for this purpose. Where ball hydrants are in use or air valves fixed, their position should be ascertained, since if polluting matter can gain access to them it is certain, sooner or later, to get into the mains. The danger of pollution arising from defective mains, ball hydrants, etc., is at a minimum when the supply of water is constant and under considerable pressure. Insuction is much more likely to occur if the supply is intermittent, but may take place even with a constant supply if the pressure varies, or if there is a contraction just beyond the defect. Moreover, with a constant supply, the water must

be occasionally turned off for repairs to mains, etc. At the point where insuction is suspected the ground should be saturated with strong fluorescein solution, and a watch kept upon the water drawn from a suitable point beyond.

Occasionally a branch pipe direct from the main is connected with the manhole of a sewer, and the water used for flushing purposes. This is an objectionable arrangement, as with a defective tap, or a tap left open, sewer air may be drawn into the mains.

The houses supplied by a particular main can be identified by injecting a solution of potassium permanganate into the main and then ascertaining the houses to which a tinted water is being supplied. In a house in which there are several cisterns the pipes from which cannot be directly traced, the tap connected with each can be identified by tinting the cistern waters with innocuous colouring matters such as potassium permanganate and fluorescein.

In some old towns water closets still exist which are flushed with water directly from the main, the "stool" tap being fixed on the seat of the closet, the end terminating within the pan itself. Insuction of filth in such cases has been proved by plugging the trap beneath the closet and filling the pan with a solution of potassium permanganate. In one recorded case the coloured liquid was drawn into the mains, yet no trace ever appeared in the water taken therefrom. Probably the permanganate was decolorised by the rust deposited in the mains, or the colour lost on account of excessive dilution.

The investigation of the distributing arrangements in a house should include first an examination of the storage cisterns (if any), to ascertain if they are constructed of objectionable material, if they are in easily accessible and suitable positions, and are clean and properly covered. Next, all the pipes communicating with the cistern should be traced, more especially to discover whether there are any direct connections with water-closets, slop sinks, or urinals, or whether there are any overflows terminating in objectionable positions. The position of the tap or taps from which drinking water is drawn should be ascertained, and the supply pipe traced to find whether the water comes directly from the main or from a cistern. The possible accumulation of masses of bacteria in the nozzle of the tap should not be forgotten.

In house supplies faulty electric wiring may have an effect upon the water. In one case in which traces of copper were found in a water, it was apparently due to the contact of an electric wire with the service pipe setting up galvanic action between the lead pipe and the brass tap. The late Sir Alex. Houston, in his report to the Metropolitan Water Board for 1910-11, commenting on the complaints received during the year, gave an illustration of this danger. He stated: "One especially interesting complaint was made during the year. The complainant arrived at the laboratories with a sample of water taken from a cistern obviously containing large quantities of copper, together with a ball valve almost completely eaten away, apparently by some corrosive agent. This was alleged to be the second ball valve which

had been similarly affected within the space of a few months. Acting on the suspicion that some electrical defects existed in the house in question, a telephone message was sent to the Engineering Department, and when inquiry was made this proved to be the cause of the trouble, two electric wires being in contact with a water pipe. The corrosion ceased immediately after the electric wires had been placed in a safe position." Several cases have come to our notice in which water has attacked the service pipes, the action being due to the utilisation of the pipes for earthing electric currents.

If any system of water purification is in use this may have to be carefully examined, and for this purpose some knowledge of the various processes is absolutely necessary. Such processes are described in later chapters.

PART III

CHAPTER VIII

WHAT CONSTITUTES A "PURE AND WHOLESOME WATER"

UNDER the Waterworks Clauses Act, 1847 (Section 35), all statutory water undertakers are required to provide a supply of pure and wholesome water. In the Public Health Act of 1936, however, no reference is made to the "purity" of water. Thus (Section 115), local authorities who supply water under this Act must secure that the water in any waterworks belonging to them—from which water is supplied for domestic purposes—is wholesome. Local authorities are further bound (Section 111), whether they supply the water or not, to ensure that the water supplies in their district are sufficient and wholesome, and that every dwelling house has a sufficient supply of wholesome water. This Act also empowers local authorities to deal with any well, tank or cistern which renders the water liable to contamination prejudicial to health.

In the law there are thus three descriptions given to water, namely, "pure and wholesome," "wholesome," and "liable to contamination prejudicial to health." While "wholesome" can safely be taken to mean "not prejudicial to health," it is doubtful whether "not prejudicial to health" means "pure and wholesome." Wholesomeness is purely a medical question, whilst purity must be physical and chemical. As a physically or chemically pure water does not occur in nature and has defied all efforts to obtain it, the law can only intend that the water should be "hygienically" pure, that is, pleasing to the senses. If more than this were intended, it would entail that the water should be free from all substances which, from their quality or quantity, were unwholesome. In this case, "pure" would signify both satisfactory to the senses and wholesome, and this is most unlikely. The water is not to be pure *or* wholesome, but pure *and* wholesome. It is possible, however, that purity may mean the absence of substances which, though not rendering the water unwholesome, are yet in some other respect objectionable, the objection being merely sentimental. It must also be remembered that the term originated before bacteria were thought of in connection with water, and when impurities were chiefly connected with water yielding excessive quantities of free or albuminoid ammonia, or of organic carbon or nitrogen. A pure water would then be one which was satisfactory to the senses, and yielded no excessive quantity of albuminoid ammonia or of carbon or nitrogen

whilst "wholesome" would signify "not injurious to health." Since the discovery of bacteria and the general recognition of the fact that they are the chief causes of "unwholesomeness" in water, our increasing knowledge of the constituents of water leads us to lay less and less stress upon the ammonias, carbon and nitrogen, since the bodies yielding these may be quite as harmless as chlorides or nitrates. Consequently, the late Sir A. Houston defined a pure and wholesome water in a way which ignores this organic matter altogether. In reference to this question the *Lancet* (January 27th, 1923) contained the following annotation, headed "What is a Pure and Wholesome Water?" :—

"Every authority responsible for a public supply of water is under statutory obligation to provide it in a 'pure and wholesome' condition. It is obvious that Parliament draws some distinction between purity and wholesomeness, but this was in the period when little or nothing was known about bacteria, and when the quality of a water was judged entirely from the chemical standpoint. A water may be considered pure chemically if it does not contain saline constituents which are objectionable either in quality or quantity and if it contains only the merest trace of organic matter. Unfortunately there are no tests which enable us to ascertain with any degree of accuracy either the quantity or character of the organic matter found in potable waters, and chemists must be satisfied with certain estimations giving an approximate idea of the quantity present. Frankland estimated the amount of carbon and nitrogen yielded by the organic matter, but the process was too tedious and delicate for general use. Later Wanklyn introduced his 'albuminoid ammonia' process, and Forchhammer the 'oxygen-absorbed' process, and both these are now universally adopted. Using these methods, chemists are accustomed to pass a water, otherwise satisfactory, if it does not yield more than, say, 1 part of albuminoid ammonia per 10 million parts of water, and if at the same time the oxygen absorbed does not exceed 1 part per million. But nothing is known of the nature of this organic matter, and experience indicates that a water yielding much higher figures may be perfectly wholesome; in fact, there is no proof that, in the absence of objectionable bacteria, this organic matter is more deleterious than that contained in an infusion of tea. Few waters which the chemist passes as 'pure and wholesome' contain more than a small fraction of a grain of organic matter. It is not unusual, however, to find that a water containing very little organic matter may come from a source liable to serious contamination, or that it actually contains bacteria indicating slight pollution with matter of intestinal origin. It may be chemically pure, yet bacteriologically impure, and therefore dangerous or unwholesome. On the other hand, since the introduction of purification by chlorine, ozone, lime, etc., a water may be rendered sterile or at least free from any bacteria indicative of pollution and yet be chemically, judged by present standards, very impure. Can such a water be deemed 'pure and wholesome'? Most would regard it as impure but wholesome, notwithstanding the apparent contradiction in terms. This is becoming a very important point, and Sir Alexander Houston, in a lecture given to the members of the Institution of Water Engineers, has defined a pure and wholesome water in such a way as to lead to the inference that a good sewage effluent, carefully sterilised, would constitute a 'pure and wholesome' water. He defines such a water as water in 'such a condition that it cannot cause typhoid fever, cholera, or other water-borne disease. It must also be free from chemical poisons and have no injurious effect on metals. Further, it should be bright, clear, and sparkling, free from suspended matter, reasonably soft, and the salts in solution should not be present in excessive amount.' Organic matter might possibly be included in 'chemical

poisons,' though it is exceedingly unlikely that the organic matter found in river waters and in part, at least, derived from sewage or manure, is poisonous or even obnoxious in the small quantity found in such waters. A good sewage effluent rarely contains more than 2 or 3 grains of organic matter in the gallon, so that the amount found in streams which may be used as a source of water supply must be and is undoubtedly much less. Unless, therefore, it is actually a strong poison or is a weak poison with a cumulative effect, the amount present in such a water which has been sterilised and carefully filtered can scarcely be harmful. Sentimentally there may be objections to the use of such a treated water, and chemists may object to its being designated as 'pure,' yet from the public health point of view it may be right to call it 'pure and wholesome,' but doubtless in some future legislation the question will be settled as to whether the designation can be accepted."

Since this article appeared Parliament has passed the Chelmsford Corporation Water Act, and section 21 states that the river water shall be so treated "as to make it comply with such standard of purity as may from time to time be prescribed by the Minister of Health." During the session (1923-4) the Southend Water Act was passed authorising the Company to take water from two comparatively small rivers and treat it by the excess lime process. The Committee refused to define any standard, and a clause similar to that in the Chelmsford Act was inserted.

In recent years, river sources have been sanctioned by Parliament without such prescribed standard of purity, since the responsibility of supplying "a pure and wholesome" water is a definite statutory obligation of any water authority.

At the present time we have not the slightest reason for suspecting that the organic matter in solution in a river water has any more effect than the nitrates formed from the complete oxidation of such matter, or that, unless in excessive amount, it affects the quality of the water any more than the nitrates and chlorides derived from the same source. It will be, however, as difficult to fix a standard for the organic matter as it is to fix a standard for chlorides, nitrates, or hardness. Again, waters of peaty origin contain large amounts of organic matter in solution, and there can be no doubt that this organic matter, which is very resistant to oxidation, is found to a lesser or greater extent in all water and is originally of vegetable origin. We are, therefore, of opinion that water taken from a properly protected river and submitted to an adequate system of purification can be rightly designated as "pure and wholesome" if it is free from visible suspended matter, colour, odour, and taste, from all bacteria of a type indicating the possible presence of disease-producing organisms (as the actual presence of these organisms can rarely be proved), and contains no matter of mineral origin which in quality or quantity would render it dangerous to health. The same would apply to water from any other properly protected source, be it well, spring, or surface water.

Turbid waters, or waters containing visible suspended matter, need not be unwholesome, but they are not pure; in any case, they are objectionable to sight, and when animalculæ, or other forms of life, are visible, the appearance may be nauseating. Gritty material may be

irritating to the bowels, and if ova are present it may be impossible to say that none will develop into worms in the intestines of the people drinking such water. Obviously such waters need filtration to remove this objection, and in their unfiltered condition they cannot be considered pure. Many waters, however, may not contain anything definitely recognisable by the naked eye, or even under the microscope, yet be faintly opalescent. This is usually due to the presence of a trace of clay or ferric oxycarbonate. Here the substance causing the objectionable appearance may be quite harmless, but a "pure" water should not have even an opalescence. It may be passed as a wholesome supply for a house, but it would not be a "pure and wholesome" water where-with to supply a town.

Coloured waters are always objectionable, and inasmuch as the colour can be removed, it should be removed at least to such an extent that the colour is not obvious in an ordinary tumbler, before the water is classed as "pure." A peaty water may be perfectly wholesome, but so long as it retains an objectionable colour it cannot be considered "pure." If people prefer to use such water rather than pay a little more and have its colour removed, there is no objection on account of wholesomeness, but the water so provided should not be termed pure.

A water with any kind of odour should be considered impure so long as it retains this odour. When the odour is due to a trace of sulphuretted hydrogen, which passes off on exposure to air, the water should be treated before being supplied for domestic use. Some waters, especially when warmed, have an odour of "soapsuds" or "earth," but if this is not perceptible to an ordinary observer, such slight odours should not, *per se*, be regarded as rendering the water impure. In the majority of cases, however, there will be found other reasons for classifying such waters as impure, if not unwholesome. Samples sent for examination are often put in bottles which have contained odorous substances, such as ammonia, disinfecting liquids, beer, wine or spirits, and occasionally the bottles are closed with corks which may be mouldy or odorous. Such samples should never be examined.

A water with an objectionable taste would be decidedly impure, but there are numerous waters with a faint chalybeate taste, or with a salty flavour about which there might be differences of opinion. Tastes differ—some people can detect the taste of salt in water containing 40 grains of sodium chloride per gallon; others would scarcely notice it with 100 grains. Moreover, many persons can detect a taste when they know that a certain substance, for example, chlorine, iron or salt, is present, but fail to detect it without that knowledge. Where the taste is so doubtful that ordinary consumers do not notice it, it may be ignored, but if it is observable by everybody the water should be classed as "impure," however wholesome it may be.

Of the saline constituents a few are objectionable even when present in the smallest quantity, others only if present in such unusual quantities as to relegate the water from the "potable" to the "medicinal" class.

Sodium Chloride is present in probably all potable waters. Lauder Brunton says of it¹: "It forms a large proportion of the salts of the body, and no doubt plays a very important part in tissue change. When persons are deprived of it for a length of time, the longing for it becomes intense, and animals will go very great distances to obtain it. When mixed with water in the proportion of 0.65 per 100, the solution does not destroy animal tissues like water alone. . . ." An excess of salt induces thirst, but long before this amount is reached, or the proportion of 650 per 100,000, the water has a distinct taste, and would be rejected. It is considered that under 100 grains of salt per gallon should not cause a water to be considered impure or unwholesome. The experience of certain communities in Essex supports this view, as waters containing 100 grains of salt per gallon (= 140 parts per 100,000) have been in use for many years without any noticeable effect, except that a saline taste can be detected by some consumers.

It is estimated that the average daily intake of salt obtained from a normal adult diet approximates to 15 grams, but probably not more than 5 grams are essential.

Chlorides of Calcium and Magnesium. Small quantities of these salts are found in many waters, including those derived from the Chalk, and from the Keuper Beds of the New Red Sandstone. Increased quantities are found in waters contaminated by sea-water. They are also found in water passed through an inadequately washed zeolite softening plant. Calcium chloride has been used medicinally in doses of 5 to 15 grains, but it now has little, if any, application. Magnesium chloride is not, so far as we are aware, used in medicine. In natural waters, these salts are invariably associated with much larger quantities of other calcium and magnesium salts, and sodium chloride. These together may render the water too mineralised for drinking and domestic purposes, but we recall no instances in which calcium and magnesium chlorides alone have sufficed to render a water unwholesome.

Nitrates of Sodium and Potassium. Nitrates are present in most waters, but practically their only concern with purity and wholesomeness relates to considerations of pollution by sewage or manure, since they may be derived from the oxidation of nitrogenous organic matter of animal origin. Nitrates are little used in medicine, but potassium nitrate can be prescribed in doses up to 20 grains when it is said to act as a diuretic. A most exceptional concentration of nitrates in water would be required to be toxic or irritant, and no such case has come within our experience. There is little doubt that in the event of such a high nitrate content other considerations would condemn the water in its use for drinking purposes. Highly nitrated waters are sometimes greatly esteemed by consumers on account of palatability, and we have known of shallow well waters containing 10 or more parts per 100,000 of nitrogen in nitrates being used for many years without complaint.

In considerations regarding wholesomeness the plumbo-solvent property of some hard, but highly nitrated waters, should not be overlooked.

¹ "Pharmacology, Therapeutics, and Materia Medica."

Sulphates of Sodium, Potassium and Magnesium. Waters containing appreciable quantities of these salts—and they are usually associated—are classed as “sulphated.” They are largely used, and waters are quite common which, whilst containing sulphates in insufficient quantity to be medicinal, yet are unsuitable for domestic or drinking purposes. In nearly all these waters the magnesium salt predominates (in some cases the alkalies may be entirely absent), and its aperient action may affect children, especially in hot weather or hot climates. These waters are common in Essex, and one well yielding water containing 120 pts. MgSO_4 and 50 pts. Na_2SO_4 per 100,000 was used for many years, although it caused diarrhoea from time to time amongst the consumers, and even caused “scour” in cattle. Under ordinary circumstances a water containing half this quantity would be regarded as unsuitable for domestic use.

The following two cases are of interest as bearing upon the wholesomeness of sulphated waters. In the first case the water was the supply to a girls' college. Sodium sulphate was present to the extent of 60 to 70 grains of the crystalline salt per gallon of water. It was the only constituent in the water which might be objectionable, and it seemed practically impossible to obtain any other supply. The question therefore, was simply whether the amount of this salt imbibed would have any effect upon the health of the children. Assuming that each child drank 3 pints of water daily, about 25 grains of sodium sulphate would be taken into the system. The dose given in “Squire's Companion” to the British Pharmacopœia is “30 to 120 grains for repeated administration, for a single administration $\frac{1}{4}$ to $\frac{1}{2}$ an ounce.” About a minimum dose, therefore, was being taken daily. The same authority also states: “In small repeated doses it is especially well adapted for cases of constipation associated with gout and hepatic dyspepsia.” The evidence of the medical officer to the institution was to the effect that the water had been used for years and he had no reason to regard it as unwholesome. During the many years he had attended the scholars he had not suspected the water as being the cause of any derangement. Under these circumstances we saw no reason for expressing an adverse opinion upon the water.

In the second case a water containing magnesium sulphate equivalent to 42 grains of the crystallised salt, and sodium sulphate equivalent to 42 grains of the B.P. sulphate, in each gallon, was proposed to be used for the purposes of a public supply to a town in the tropics. Considering the amount which might be imbibed daily under tropical conditions, and the prevalence of choleraic diseases in the locality, the opinion was expressed that it was not a suitable water for domestic purposes. The hardness and salinity (it contained also some 30 grains of common salt per gallon) rendered it unsuitable for boiler and manufacturing purposes.

Sodium Carbonate. This salt occurs occasionally in waters from the most diverse geological formations, but is especially common in the London Basin in the waters derived from the Lower London Tertiaries and the Chalk beneath. The amount present may vary from 2 or 3

parts to 50 parts of carbonate per 100,000, the latter approaching in character some of the greatly esteemed "table" waters. These alkaline waters have been used over large areas for generations, and are of the highest repute for their purity and wholesomeness. In a paper contributed to the *Lancet* (October 11th, 1913) the death returns were compared for districts (a) using the soft alkaline waters, (b) districts using the moderately hard non-alkaline waters, and (c) districts, using hard waters. The conclusions arrived at were (1) that the alkaline waters are perfectly wholesome, as wholesome, in fact, as any other waters, and (2) that the filtered and hard waters derived from the sewage-polluted waters of the Thames and Lee, as supplied by the Metropolitan Water Board, are as wholesome as any other water in the country.

A careful study of the sickness and death returns for the county of Essex for a series of years failed to show any undue incidence of disease among the drinkers of the soft alkaline waters over those using any other kind of water, and therefore we concluded that a soft water of this character is as wholesome as a hard water. It has since been ascertained, however, that some of these alkaline waters contain a trace of fluoride on account of which they cause the dental defect known as "mottled teeth."

The question of the effect of sodium carbonate with or without a comparatively small amount of sodium sulphate assumed considerable importance in consequence of the introduction of the base-exchange system of water softening. A large water company, desirous of adopting this process, requested us to consider the question so far as it related to their water supply, and we reported that the softened water would be perfectly wholesome. The following is a copy of one of the reports thereon by Dr. Thresh, who was then Medical Officer of Health for the County of Essex :—

"I have made a considerable number of experiments with Permutit, using hard waters from various sources, and have made analyses of the waters before and after softening. The results show that all the lime and magnesia salts are removed and soda salts substituted, that is to say, that the hard waters containing carbonates and sulphates of lime and magnesia become converted into soft waters containing no salts of lime or magnesia, but amounts of carbonate and sulphate of soda corresponding to the lime and magnesia salts removed.

"Assuming that a water had 30 degrees of hardness, a very excessive amount, and that it has passed through Permutit, the hardness will have entirely disappeared and the water will then contain about 25 to 30 grains of carbonate of soda per gallon. The question, therefore, is whether this amount of soda salts will affect the health of those who drink the water.

"Fortunately I am in an exceptional position for giving an opinion upon the point, as waters containing considerable quantities of soda salts are used for public supplies in many towns in the county for which I am Medical Officer of Health, and I have recently been able to prove

that these waters ¹ are derived from very hard chalk waters which have undergone Nature's softening process, and that Nature's process is exactly the same as that of Permutit. The Thanet sands under Essex and London contain a small quantity of a mineral allied to Permutit, and when very hard waters are slowly passed through they become softened. A cubic foot of Permutit, however, will soften many gallons of water in a few minutes, whereas it would take a cubic yard of Thanet sand many hours to produce the same softening effect. As these soft waters are used by about 100,000 people in this county, I am able to give an opinion based upon actual experience extending over twenty years, and that opinion is that these softened waters are perfectly wholesome, as wholesome as any other water occurring in Nature.

Name of Waterworks	Population supplied	Death rate for last 10 years	In grains per gallon		Total	Estimated hardness of original water
			Sodium carbonate	Sodium sulphate		
Gt. Baddow . . .	5000	12 (<i>abt.</i>)	24.0	5.7	29.7	26.7
Benfleet . . .	7500	12.6	18.8	6.5	25.3	23.0
Braintree . . .	5330	15.0	14.0	8.5	22.5	19.4
Wyvenhoe . . .	3000	9.3	12.6	9.9	22.5	19.6
Burnham . . .	3200	11.7	23.9	6.6	30.5	27.3
Maldon . . .	5700	14.4	26.0	6.4	32.4	30
Witham . . .	3640	12.0	18.7	7.6	26.3	22.8
Broomfield (Works approved by L.G.B., but not yet completed)						
Southend . . .	70,000	12.0	25.0	5.8	30.8	28.3
Heybridge . . .	2000 (<i>abt.</i>)		19.6	7.0	26.6	24.5
Chelmsford (partial supply) . . .		13.3	21.7	9.1	30.8	28
Writtle . . .	2000 (<i>abt.</i>)	13.3	24.8	7.0	31.8	28.7
		13 (<i>abt.</i>)	22.8	9.5	32.3	29.0

Average death-rate for the whole county for the past 10 years = 13.1.

"I have just completed the analyses of all the public water supplies in the county of Essex, and from the quantities of carbonate and sulphate of soda present in the soft waters I have calculated the original hardness of the waters from which they are obtained. These are given in the above table, and I have also added the average death rate for the districts for the past ten years.

"During the twenty years I have had these districts under observation there has never been the slightest reason to suspect that any of the above public water supplies were of anything but the most wholesome character. In many parts of the county we have small local supplies containing much more of the soda salts, and they are equally wholesome. The most popular table waters in the world are waters which contain larger quantities of the above soda salts, and a large proportion of the members of the medical profession regard them as more suitable for drinking purposes than ordinary hard waters.

¹ *The Lancet*, February 3, 1912.

"Natural seltzer water contains about 58 grains of carbonate of soda per gallon.

"Natural Apollinaris water contains about the same quantity.

"A natural water bottled at Peterborough contains about 40 grains of carbonate and $12\frac{1}{4}$ grains of sulphate of soda, and is very highly spoken of by the *Lancet* (February, 1904), in whose laboratory the analysis was made.

"There can be no question, therefore, that waters softened by the Permutit process are perfectly wholesome, assuming, of course, that the waters originally were free from polluting matters of a dangerous character."

The water company adopted the process, and installed the first municipal base-exchange softening plant in Great Britain (1912), and to-day many other public water supplies are softened by this process with satisfactory results.

Calcium and Magnesium Carbonates and Sulphates. In practically all cases the hardness of a water depends upon the presence of these salts, the "temporary" hardness being due to the carbonates, and the "permanent" to the sulphates. There are some persons who acknowledge the wholesomeness of a water if the hardness is of a temporary character, yet look with suspicion upon waters with a high permanent hardness, and there are still a few who think that hard waters, whatever the nature of the hardness, are not so wholesome as soft waters, and there is probably an equal number convinced that soft waters are not so wholesome as hard. It has also been alleged that magnesium salts are more objectionable than calcium salts.

Calcium is the most important and abundant mineral constituent of the human body, and an adequate intake is essential for normal growth and health. The minimum average daily requirement of calcium is probably 1 to 2 grams, the larger amount for mothers and children, and normally this is amply supplied by a diet of ordinary food-stuffs, particularly dairy products and vegetables. Magnesium is of less importance, but the average daily requirement of man is probably of the order of 0.3 to 0.5 gram, and this also is amply supplied by ordinary articles of diet.

Considered as a whole, public water supplies play no material part in the supply of these essential substances.

Dr. Lewin has dealt with waters of temporary hardness in a paper contributed to the Section of Balneology and Climatology of the Royal Society of Medicine (*British Medical Journal*, July 22nd, 1911), entitled "On the Influence of Calcareous Drinking Waters in Health and Disease." He sums up the results of his investigations and observations very tersely, thus: "There is no evidence that hard water has any bad effect; on the contrary, all the evidence is the other way." Logically this conclusion means that the evidence is in favour of hard water being more wholesome than soft.

Excessively hard waters have been alleged to cause kidney disease, dyspepsia, etc., but on most unreliable evidence. A French Com-

mission arrived at the conclusion that a moderately hard water was the best, and that persons residing in districts supplied with such water had a better physique than those living in districts where soft water was used, and a Vienna Commission expressed the same opinions. The River Pollution Commissioners, after a lengthy investigation, came to the conclusion that, "where the chief sanitary conditions prevail with tolerable uniformity, the rate of mortality is practically uninfluenced by the softness or hardness of the water supplied to different towns, and the average rate of mortality in the different water divisions varies far less than the actual mortality in the different towns of the same division." The late Dr. B. Ward Richardson believed that the hard waters in certain watering-places often affected the health of the visitors, causing dyspeptic symptoms. Probably this temporary indisposition is merely due to a change in the character of the water used, since we have found exactly the same series of symptoms to occur in watering-places where the water is very soft, amongst the visitors who have been accustomed to the use of hard waters. The Loch Katrine water, which is very soft, is said to have caused an increased prevalence of rickets in Glasgow, but there is no vestige of proof that such is the case.

In connection with this subject, the following experience may be worth recording. At a large county asylum a water-softening plant was installed to prevent the furring of boilers and hot-water pipes. The process softened the water, but probably on occasions the lime was added in excess. The medical officer wrote, complaining that since the softened water had been in use there had been an increased prevalence of dyspepsia.

Some years ago the medical officer to the Eastern and Western Telegraph Companies consulted us respecting several of their stations in tropical climates where the only water available was the distillate from sea water. At these stations he had found that the teeth of their men were markedly affected, and he wished some simple process devised whereby a small but uniform quantity of calcium carbonate could be introduced into the water. As the result of experiments, the following process was devised for treating each 100 gallons of water distilled, this being the capacity of their distilling apparatus. In the freshly distilled water (100 gallons) 2 ounces of crystallised calcium chloride are dissolved and the water agitated, then $2\frac{1}{2}$ ounces of sodium bicarbonate are added and the solution is stirred whilst the salt is dissolved. This results in a water containing about $5\frac{1}{2}$ grains of calcium carbonate and $6\frac{1}{2}$ grains of sodium chloride per gallon, the calcium salt existing in solution as bicarbonate.

It is possible that during the distillation of the sea water a little hydrochloric acid is liberated and distilled over. If such is the case, the sodium bicarbonate will neutralise it with the production of a little more sodium chloride, the presence of which is probably also an advantage. A distilled water, treated in this way, appears to be more palatable than the original water.

In Parliament the question is often raised as to what degree of hardness is permissible in a potable water, and in one instance it was decided that a water of about 22° (Clark) should be softened, more especially because several degrees of this hardness were due to magnesium salts, which Sir James Dewar contended were more detrimental to health than lime salts. In such cases private practitioners are always called who allege that they have more patients suffering from gastric derangements in the hard-water districts than in the areas where a softer water is used, and the suggestion that renal calculi are more common amongst the users of hard water is generally made, but no facts are ever adduced showing that hard waters have any influence whatever upon health, not even when the hardness is in part due to magnesium salts. Were it otherwise, medical officers of health would have detected it. We have examined thousands of their reports for counties, boroughs, urban and rural districts, and we have not found in any single instance a medical officer who has reported any difference in the death or sickness rates between districts supplied with hard or soft waters. Of more recent date, Parliament has sanctioned the use of water of 22° (Clark) of hardness without preliminary softening.

The *Lancet*, March 28th, 1914, contains an article by Dr. J. Basil Cook on the relation between the drinking water and dental caries in school children, and his conclusions are here given :—

(1) The foregoing correlations and partial correlations indicate an association between excessive softness of water and an increased amount of dental caries amongst the school children, and obversely. (2) The association is evident, but it must be remembered that this inquiry deals only with urban districts; had it been possible to obtain reliable returns from rural districts its value would have been considerably enhanced. (3) The environmental conditions, so far as it was possible to measure them, do not seem to be a source of the relation between the hardness of water and the amount of dental caries. (4) It must be definitely and distinctly emphasised that these correlations and partial correlations merely call attention to an association between the nature of the drinking water and the amount of dental caries, and must not be regarded as necessarily indicating cause and effect. (5) There may well be other factors at work which have a greater influence, but if this investigation merely draws attention to a hitherto neglected topic it will not have been undertaken in vain.

We assisted in a local (Essex) investigation, and failed to obtain any evidence that dental caries in the county had any relation to the hardness of water supplies.

In the Special Report Series, No. 97 of the Medical Research Council (1925) on "The Incidence of Dental Disease in Children," the examination of some 4,000 school children, from town and country districts in England and Wales, is described, and on p. 24 it is stated that no significant correlation between dental caries and softness of the water supply could be obtained.

So far as the general health is concerned, therefore, the question of hardness may be regarded as settled, but the hardness does affect the suitability of a water for domestic, steam-raising, and many manufacturing purposes, and this will be referred to later.

Silica. In 99 per cent. of potable waters the silica appears to be in actual solution, and not in a colloidal state, but in what condition it is impossible to say, since it may be in combination with any of the bases usually found in water. It occurs in the largest quantities in chalk waters and in waters containing sodium bicarbonate. As it is now sometimes added to very soft waters as sodium silicate, the question has arisen whether such addition may have any effect upon health. The amount of silica present in a potable water is not always estimated, but we have examined a considerable number of private and public supplies, and find that hard waters almost invariably contain more than soft waters, with the exception of those soft waters which contain sodium bicarbonate. The amount present seems to vary from 0.1 to 4 parts per 100,000, the former occurring in moorland waters, and the latter in calcareous waters. Excluding moorland waters, the average silica content of forty samples of water recently examined was 1.75 parts per 100,000, the extremes being 0.55 in a soft water and 3.6 in a very hard chalk water.

The amount of silica added never causes the treated water to contain more than 1 part per 100,000; hence, moorland water so treated contains far less silica than the average of waters from other sources.

The alkaline silicates have always been regarded as inert, and are little used medicinally. It is a singular coincidence that the question was raised in this country as to some relation between silica and cancer just at the time that in France a surmise was hazarded that silica or some special silicate might be a preventive of cancer.

In consequence of this the cancer statistics for a number of towns have been studied, these being divided into two groups: (1) towns using water containing very little silica, and (2) towns using more highly silicated water. The conclusion arrived at was that no possible connection could be traced between the cancer death rate and the amount of silica in the water¹ used.

At present it cannot, therefore, be said that the amount of silica present in a water has any effect whatever upon its purity or wholesomeness.

Iodine and its Compounds. All attempts to connect the prevalence of goitre with water supplies or with any of the constituents of potable water have failed to yield conclusive results.

There is a large volume of opinion that iodine and goitre are in some way connected, but the part played by iodine with regard to that disease is not precisely known.

It has however been suggested by the work of investigators in various parts of the world that where goitre is endemic there is a general deficiency of iodine in all food-stuffs.

Also, the administration of iodine has in some cases led to pronounced benefit. Dosing of the public water supply has been one mode

¹ Thresh, the *Medical Officer*, November, 1923. This conclusion has been confirmed by a much more extended series of observations made by Dr. Bullough, County M.O.H., Essex.

of administration of iodine to the populace, but this method is open to much criticism.

The subject of iodine, its distribution in nature, and relationship to goitre has been extensively studied by Dr. J. B. Orr and co-workers at the Rowett Research Institute, Aberdeen, and two valuable reports thereon have been issued (see Special Report Series, No. 123, 1929, and No. 154, 1931, Medical Research Council).

No definite conclusions were reached, but the results obtained showed no correlation between the incidence of goitre and the amount of iodine contained in the water supplies.

Water supplies generally contain only infinitesimal traces of iodine, but deep well waters sometimes contain larger traces than surface waters. Minute amounts such as are ordinarily found in water are more likely to be beneficial than deleterious.

Where larger traces of iodine are present in water it will usually be found associated with other salts sufficient in amount to cause it to be classed amongst "medicinal" rather than "potable" waters.

Bromine and its Compounds. These are far more common constituents of water than iodine or iodides. All the deep well waters in Essex contain traces, suggesting some connection with sea water, which may contain 5 to 6 parts or more per 100,000, of bromine or bromide. The dose of potassium bromide being 5 to 30 grains, it is very unlikely that a potable water will ever be found to contain a significant quantity derived from this or any other source. It is quite conceivable that cases may arise where it is necessary to decide whether a water is "potable" or "medicinal" from the presence of these compounds, but such points should be referred to the medical expert, who would take the quantities and qualities of all the saline constituents into consideration.

Fluorine and its Compounds. These are rare constituents of water. Fluorine is, however, present in some waters, and appears to be harmless, or even beneficial in preventing dental caries, in amounts of less than 1 part per million, but when this quantity is exceeded the dental defect known as "mottled teeth" occurs. The consumers affected are those born and bred in the area of the supply, and the condition is prevalent in certain localised areas of Essex where the fluorine content of the water supplies varies from 3 to 6 parts per million.

Aluminium. Sulphate of aluminium has been used for a long period as a coagulant for removing colloidal matter from potable water, but, unless used in excess, no alumina is found in the water, the sulphate being decomposed by the carbonates in the water with the formation of flocculent aluminium hydrate and carbonic acid gas. So far as we are aware, one of the first waterworks at which it was used was at Ingatestone, in Essex, where 1 to 2 grains of alumina-ferric were added to each gallon of a turbid subsoil water prior to filtration. Filtration alone failed to produce a bright water. This apparently became known in America, as we received letters from the States asking if alumina was found in the filtered water and if it had any medicinal action. Since

then it has been used very largely in the United States for clarifying river water supplies, and also in this country, with great success. No record of any effect being produced on the consumers has ever been published. Sodium aluminate is also used for a similar purpose. The following extract from Cushny's "Text-Book of Pharmacology" is fairly conclusive as to the innocuous character of alumina, even if a little remained in the water: "Long continued use of alum does not elicit any symptoms of chronic poisoning. The aluminium salts are not absorbed in any quantity from the stomach or intestines, so that no symptoms of general poisoning arise from the internal use of the salt. Aluminium vessels may be used for cooking, or even to contain acids, without danger of intoxication, as has been shown by a recent series of investigations." The amount of alumina found in any water is so minute that it would appear to be without significance. Alumina is insoluble in pure water and in ordinary carbonated potable waters, but waters containing organic matter in solution may apparently dissolve a trace. In acid mineral waters the alumina is often found in solution as sulphate, but in potable waters the amount present is usually too small to estimate.

At the *Lancet* laboratory a series of experiments was made with aluminium vessels and various kinds of water, since it is well known that waters, especially if alkaline, act upon aluminium. The results were published in the issue of January 4th, 1913, headed "Some Kitchen Experiments with Aluminium," and the conclusion arrived at was "that any suspicion that aluminium may communicate poisonous qualities to food in the process of cooking may safely be dismissed." As food during cooking may take up vastly more aluminium than is ever found in a potable water, it is most unlikely to be harmful as a constituent of water supplies.

The subject has been reviewed by Dr. J. H. Burn, formerly Director of the Pharmacological Laboratories of the Pharmaceutical Society of Great Britain, in Research Report, External Series No. 162, "Aluminium and Food," issued by the British Non-Ferrous Metals Research Association, 1932.

His conclusions accord with the opinion expressed above, and, in view of the reports to the contrary,¹ we quote the concluding pages, 27-29, of his Report.

"Fortunately the widespread interest which the possible danger of aluminium in food has aroused has led to investigations by workers of the highest standing, whose considered opinion, apart from their experimental results, should be a sufficient guide for others. The report published by the United States Department of Agriculture has already been fully discussed (see later); it is a document which should by itself be sufficient to dispel the anxiety of all reasonable people, based as it is on experiments on human subjects. The paper published by Professor E. V. McCollum² and his collaborators should have similar weight; his opinion that aluminium in

¹ "The Danger of Food Contamination by Aluminium." Le Hunte Cooper, 1931, John Bale, Sons & Danielsson, Ltd., London, and subsequent discussions and correspondence in *British Medical Journal*, 1931 and 1932.

² McCollum, Rask and Becker, 1928, *J. Biol. Chem.*, 78, p. 615.

food of rats has no harmful effect on growth and reproduction is evidence likely to satisfy all workers on nutrition, who are the people most competent to judge on this question.

"Among pharmacologists, whose special work demands a knowledge of the toxicities of different substances, the opinion has been repeatedly expressed that aluminium is harmless. Sollmann's 'Text-book on Pharmacology' (published in United States, 1922) says, 'The quantities which may be dissolved from aluminium cooking vessels, even by dilute acids, are too small to be of any importance.' Poulsson's 'Text-book of Pharmacology' (Oslo, 1923) says that the 'present employment of aluminium for cooking vessels is productive of no danger to health.' Cushny's 'Text-book on Pharmacology and Therapeutics' (Edinburgh, 1924) says 'aluminium salts are only absorbed in small quantities from the stomach and intestines, so that no symptoms of general poisoning arise from the internal use of the salts. Aluminium vessels may be used for cooking, or even to contain acids without danger of intoxication.' C. W. Edmunds, Professor of Materia Medica in the University of Michigan, speaking of food prepared in aluminium containers, says: 'The conclusion which has been drawn from these elaborate and laborious researches is that the use of such utensils and containers is not attended by any risk of health, and that any fears upon this score may be dispelled.'

"If these views are true, it may be asked how does it happen that people are restored to health by discontinuing the use of aluminium vessels for cooking their food? Reports of this kind have recently been circulated by Le Hunte Cooper (1931). It is a commonplace of medicine to-day that every new remedy which is introduced brings a striking improvement in a small number of patients, although the majority of these new remedies are soon recognised to be worthless.

"There are many pharmaceutical firms, in this country and especially abroad, who introduce new remedies almost every week, and every one of these is found to be of great benefit by a few doctors. It cannot be disputed that this benefit is real in spite of the fact that the same doctors soon find that for most patients the remedy is useless, and that sooner or later they cease to use it. The reports of benefit arising from discontinuing the use of aluminium cooking vessels are exactly like the reports of the value of new remedies. How these reports are to be explained is a mystery which we cannot understand, but the existence of which must be recognised; the mystery is the mystery of the effect of mind over body, and of the power of the witch doctor since civilisation began. In view of the clear evidence provided by the numerous nutritional and pharmacological researches that aluminium cooking utensils are harmless, it is certain that benefit arising in patients from the discontinuance of aluminium cooking vessels is entirely due to the patients' psychological reaction to the doctor. Provided the doctor believes that these vessels are dangerous, he will observe benefit in a few patients from discontinuing their use; but the benefit depends on the doctor's conviction, and is a benefit due to psychological forces only.

"Reports have been circulated that aluminium cooking vessels are a cause of cancer. These reports are, of course, sensational inventions. Knowledge of the cause of cancer is at the present time extremely small, and many workers have patiently investigated the cause for years past; efforts to produce cancer by chemical means have been repeatedly made, and it is known that coal tar and soot can produce cancer. These agents have been much used to produce cancer experimentally in order to study other factors which may delay or prevent the new growth. If it were true that aluminium compounds could cause cancer, the discovery would be one of the greatest immediate value to all those engaged in the study of cancer, for they could use aluminium compounds instead of tar to produce cancer experimentally in mice. The statement that aluminium cooking vessels may give rise to cancer is as foolish and mischievous as it would be to say that the wearing of artificial silk causes cancer.

"The final conclusion is in no doubt that aluminium cooking vessels offer no danger to health. When aluminium salts are taken by mouth, small amounts are absorbed into the blood and tissues; it is, however, a peculiarity of aluminium salts that, except when very large amounts are directly introduced into the body by injection, they produce no harmful effects. When aluminium cooking vessels are used, the amount of aluminium salts which enters the food is not more than a small fraction of a grain a day, and of this only traces are absorbed into the tissues; these have been repeatedly shown to be harmless."

The conclusions expressed in the Report of the United States Department of Agriculture, 1914, Bulletin No. 103, referred to above, were that the presence of aluminium compounds in foods had not been "found to contribute any poisonous or other deleterious effect." (Amounts of aluminium up to 2.31 grains daily.)

The conclusions of these various workers doubtless apply in the majority of cases, but they cannot be accepted as final. Aluminium is foreign to the human body, and it is possible that an unusually small intake may cause symptoms in certain hypersensitive individuals forming a very small minority of the community.

The complaints which mostly come to our notice concerning the use of aluminium utensils are of green-blue discoloration of the carbonate deposit which is formed when hard water containing minute traces of copper derived from domestic pipes is heated therein.

Complaints of unduly rapid corrosion and perforation of aluminium appear to arise most commonly with alkaline waters containing sodium bicarbonate.

Aluminium is not used for water mains and pipes, but sometimes forms part of water-heating apparatus.

Zinc. Whilst iron and zinc are very frequently found in potable water, lead occurs less frequently, and copper only occasionally. We have seldom found a natural water containing zinc in solution, though possibly in localities where zinc ores abound such may frequently occur. If zinc is found in a natural water, it must be considered as an impurity. There is no doubt that waters acting upon zinc, and containing traces of this metal, are more common than is usually supposed, yet they have been used continuously for long periods without causing any obvious ill-effects. The water supply to a small hospital invariably contained a trace of zinc, probably never more than $\frac{1}{2}$ grain of the carbonate per gallon, but no indications of deleterious effects were ever observed, although they were looked for. The source of the metal was a length of galvanised iron pipe which led from the water main in the road, about a quarter of a mile away. In another instance a sample of water was examined because the medical attendant of the family using it suspected that it caused constipation, and we found that it contained about 3 grains of zinc carbonate per gallon, derived from a galvanised iron pipe which had recently been laid to convey water from a distant spring to the house. A year afterwards the water was again examined, and found to contain large traces of the metal. The waters which exhibit this zinc solvent power may be soft or hard, but usually the

temporary hardness is under 4 parts per 100,000 and the waters contain free carbonic acid. In another case, in which a well water acted upon zinc, the temporary hardness was 8 parts per 100,000, and the amount of zinc present corresponded to 1 grain of carbonate per gallon.

In 1915 the matter assumed considerable importance, since early in the War galvanised iron pipes were sent abroad for use in connection with military water supplies, and the Army analysts, finding zinc in the water delivered by these pipes, became alarmed. We made an extended investigation for this and other reasons, and the result was an article published in the *Lancet* of November 13th, 1915, which is here reproduced:—

Zinc in Potable Water

Has it any Effect upon Health?

Within the last few months the question of the effect upon health of small quantities of zinc in potable waters appears to have become a matter of some importance, since I have been consulted on several occasions recently with reference thereto by both military and civil authorities. The views held generally caused me great surprise, as apparently it is not known that zinc is found in nearly all waters which have passed through galvanised iron pipes, and therefore is frequently found in potable waters if sought for, and it is also generally believed that its presence in water, even in small quantities, is likely to prove injurious to health.

Few analysts take the trouble to test for zinc, and as to its effect upon health the text-books either make no reference to it, or state that it is an undesirable constituent. In one text-book on toxicology there is an account of an outbreak of acute intestinal irritation which occurred in one of our dependencies, and which the medical attendant attributed to the presence of zinc in the water used by the patients. Had the water contained twenty times as much arsenic as it did zinc, it is doubtful whether it would have caused such serious illness, and the possibility of there being any other cause for the illness is not even referred to. In a recent issue of a sanitary journal a writer states that "zinc, though not so poisonous as lead, may cause serious symptoms of irritant poisoning to persons drinking water in which it is dissolved."¹

Galvanised iron pipe is used in enormous quantity for service pipes conveying water from the mains to supply consumers, and as practically every natural water acts more or less vigorously upon the zinc lining of such pipe, there ought to be no difficulty in discovering the effects of the metal, assuming these are of a deleterious nature. I have never heard of a water containing zinc possessing any irritant properties. In my work on "Water Supplies" will be found recorded a case where a water containing about 3 grains of carbonate of zinc per gallon appeared to have caused *constipation* in some young children using it. It had no effect upon the adults in the establishment. I have never heard of any irritant effects, although I have made inquiries amongst a large number of families who for many years have used water containing very appreciable quantities of zinc. In connection with a case which recently came before a divisional bench, appealing against the decision of a local sanitary authority which had refused to grant a certificate for the occupation of a group of recently erected cottages because the water contained from 0.1 to 0.2 grain per gallon of zinc, the magistrates, after hearing the evidence, ordered the authority to grant the certificate and mulcted them

¹ No proof is adduced of this extraordinary statement, nor have I ever heard any proof beyond that of the utterly improbable outbreak referred to above which no doubt was due to food.

in £50 costs. In connection with this case Dr. R. A. Lyster, medical officer of health of the county of Hampshire, in which county the case arose, collected a number of samples of water from different parts of the county where galvanised iron service pipes are in use and found zinc in all, on occasions the amount exceeding that found in the implicated water. In many instances the water had been in use for years and, even in large establishments where any effect would be most likely to be observed, no suspicion of any harmful effect had ever been raised.

In connection with this case I selected a number of places in different parts of Essex where I knew the water contained appreciable quantities of zinc and where such water had been used continuously for long periods. Samples of water were collected and inquiries made of the consumers, of the local medical practitioners, and the medical officer of health. Where the water contained an unusually large quantity of zinc, I made inquiries at each house using it and saw most of the members of the family, especially the children. There was not a tittle of evidence forthcoming that the water caused intestinal irritation, or constipation, or any other recognisable effect.

The amount of zinc present in potable waters which have passed through but short lengths of galvanised iron service main rarely amount to $\frac{1}{10}$ grain per gallon, but the waters concerning the effect of which my inquiries were directed contained from $\frac{1}{8}$ to about 2 grains per gallon. The following may be cited as examples of water which has passed through considerable lengths of zinc-coated piping :—

Premises supplied.	Length of galvanised iron service pipe in yards.	Amount of zinc present in grains per gallon.
1. Farm and cottages . . .	400	0.8
2. Railway station and cottages . . .	900	0.8
3. Farm and cottages . . .	830	0.5
4. Rectory . . .	400	0.3
5. Farm and cottages . . .	800	0.5
6. " " . . .	400	0.3
7. " " . . .	700	0.6
8. " " . . .	900	0.6
9. An isolation hospital . . .	450	0.3
10. Group of cottages . . .	600	0.07
11. A mansion . . .	400	0.12
12. Factory and houses . . .	100	0.8
13. Farm premises. . .	100	0.25
14. Small hamlet . . .	700 to 1,000	0.7 to 1.6

The amount of zinc found in these waters varies considerably, the chief factor being the time which the water has been in the pipe. In all the above cases, except No. 14, the water was taken in the early morning, and in a few instances may be above the minimum, or even above the average, but in No. 14 the amounts represent the average, or may even be below the average, and are therefore worth further consideration, as the amount of zinc is unusually large.

The hamlet in question is on the London clay, and until 1905 water was only obtainable at a considerable distance. In that year a public supply was inaugurated, the water being obtainable from a spring on the hillside nearly 1,000 yards away. This water was collected in a galvanised iron tank and conveyed through galvanised iron pipes to supply a farm, nine cottages, and a public elementary school. When the works were completed, a sample of the water taken from one of the three standpipes erected was sent to me for examination. I found that it contained approximately 2 grains of zinc per gallon, and I pointed out to the medical officer of health that this was an unusual quantity, and that it might cause constipation amongst children

using it. I sanctioned its use, at the same time expressing the opinion that the amount of metal in the water would decrease. Since the date above mentioned this water has been the sole supply for the hamlet, and the medical officer of health always assured me the water was quite wholesome. In October last I obtained a sample, and found that it contained 1.6 grains of zinc per gallon, the sample being collected during the afternoon from the standpipe farthest from the spring. I wrote to the medical man practising in the neighbourhood, and he assured me that he had never had any case of illness in the hamlet which he could attribute to the water, nor did he think either children or adults suffered more from constipation or from intestinal irritation than persons residing elsewhere. I visited the hamlet and saw every man, woman, and child who could be found, and I collected samples of water from two hydrants, one the nearest to the spring and the other the farthest away. The time was 11 a.m., and I was assured that most of the day's supply had then been drawn. The water from the former was subsequently found to contain 0.7 grain of zinc per gallon, and the latter 1.25 grains.

The inquiries made confirmed the conclusion arrived at by the medical officer of health and the medical practitioner—namely, that the water was perfectly wholesome. We have, therefore, a small community of people of all ages who have used for ten years no other water but this, which contains from 0.7 to 1.6 grains of zinc per gallon, and yet have suffered no injury to health.

It is perfectly obvious, therefore, that the statements made about the injurious effects of small quantities of zinc in potable water are entirely without foundation. Personally, I would rather drink habitually a water containing 2 grains of zinc per gallon than one containing the same amount of iron, and I really see no reason for believing that this quantity of zinc would harm anyone.

In conclusion, it may be of interest to point out that galvanised iron is largely used in London, and that the Thames and Lee derived waters supplied by the Metropolitan Water Board attack zinc and dissolve it in appreciable quantities. Water drawn first thing in the morning at my laboratories contains an easily detectable trace of zinc, and this water, when left in contact with zinc, dissolves from 0.4 to 0.8 grain per gallon, the larger amount being from pure distilled zinc, and the smaller from commercial zinc. The property of dissolving this metal is not, therefore, confined to soft waters, but the cause of the action is a subject foreign to the purpose of this brief paper.

In every sample of water examined the zinc appears to have been in solution as bicarbonate, as the whole is thrown out of solution by continued boiling. With reference to the carbonate, Taylor, in his work on "Poisons," says: "It does not appear to have any poisonous action; and it would probably require to be given in large quantity to produce any effect." No evidence is available showing that zinc can accumulate in the system; in fact, it appears to be quickly eliminated. Doses of zinc, larger than the amount contained in several gallons of zinc-contaminated water, have been given three times a day for several consecutive weeks without producing any appreciable effect. It follows, therefore, that there are no *a priori* reasons for believing that such small quantities of the metal as are found in potable waters would cause any disturbance of the bodily functions.

In an "annotation" reference was made to this article, stating:—

It does not appear to be generally known that zinc is invariably found in the majority of waters which have passed through galvanised iron pipes. It is reassuring to learn, however, from a communication which we publish this week from Dr. John C. Thresh, that the quantity of zinc dissolved contributes no harmful property whatever, and in his view the statements made about the injurious effects of small quantities of zinc in potable water

are entirely without foundation. As far back as March 1st, 1884, the *Lancet* published a note on the occurrence of as much as 6.41 grains of zinc carbonate per gallon in a drinking water supplied through about half a mile of galvanised iron pipe from the source to a Welsh village, but no reference was made in this case to any ill-effects having been observed, although the matter was in the hands of the medical officer of health. The water at the source contained no zinc, and only 10.8 grains per gallon of total solids. At the point of delivery, however, the total solids were increased to 18.9 grains, the increase being largely due to the amount of zinc taken up. It is to be noted that Dr. Thresh confines himself to refuting the statements as to the injurious effects of small quantities of zinc, and in the results he records that the amount of zinc found did not exceed 2 grains, while in most cases it rarely amounted to more than 0.8 grain per gallon calculated, we presume, in terms of metal. Broadly, 1 part of zinc would be equivalent to 2 parts of the carbonate, so that the water mentioned in the *Lancet* of 1884 would contain 3.2 grains of metallic zinc, the equivalent of 6.41 grains of the carbonate. This quantity exceeds that detected in any case by Dr. Thresh.

Zinc is not a desirable constituent of a potable water, and if it is present in an appreciable amount, say, 0.5 part per 100,000, the water may be regarded as impure, but doubt could be expressed as to whether the water was unwholesome. With more than this quantity its use could not be advised, although under circumstances rendering an alternative supply impracticable it can be pointed out that waters containing on occasions 2 or more grains of zinc per gallon are being used, and apparently with impunity. Although usually the amount of zinc dissolved by the water gradually decreases with time, this is not invariably the case, and the amount found at any given time may not represent an average. We had samples taken from a pipe which had yielded about 1 grain of zinc per gallon, but after a few gallons had been drawn off quickly the metal present was only about 0.01 grain per gallon. A manufacturer of galvanised iron pipes informed us that the amount of zinc deposited on the tubes galvanised averaged 1 ounce per square yard of surface in 1-inch tubing. In one case, where a special sample was found to contain a certain amount of zinc and the pipe had been in use for many years, a simple calculation showed that, if this had been an average sample of water, the whole of the zinc would have disappeared years ago. The action can often be prevented or greatly reduced by passing the water through chalk or magnesite. In one case, where chalk was placed in the receptacle collecting spring water, the amount of zinc dissolved was reduced by 90 to 95 per cent.

Salts of zinc are rarely, if ever, prescribed for internal use, but the United States Pharmacopœia gives the dose of the carbonate as 2 to 8 grains. Cushny, in his "Pharmacology," however, has the following interesting remarks about the effect of zinc salts:—

"The insoluble zinc oxide and carbonate are less likely to cause irritation than the sulphate, but their prolonged ingestion has given rise to dyspepsia and constipation or diarrhœa in some cases. The continued administration of zinc salts has no effects in man, except those of disordered digestion and constipation, and Lehmann could detect no effect in the dog after the administration of 155 grams of the

carbonate in the course of 355 days, although a considerable amount of the metal had been absorbed."

Iron. This metal is one of the most frequent constituents of potable water, but fortunately it usually occurs in such minute quantities that its presence can be ignored. Whenever it occurs in large amounts it imparts a bitter taste to the water which is so objectionable that no one would willingly drink it, and it could not be considered as pure, although the amount present may not be sufficient to cause the water to be unwholesome. There are also so many other objections to its presence, such as the production of discoloration and turbidity, that the question of wholesomeness rarely, if ever, arises. In no water which can be considered potable should there be more than 0.05 parts per 100,000 of iron, and this amount cannot possibly have any effect upon health. The smallest dose of carbonate for a child is about 1 grain, equivalent to 0.5 grain of iron, and 14 gallons of water containing 0.05 parts per 100,000, would contain less than one dose. Iron is one of the essential elements to the human body and is taken in appreciable traces in ordinary food-stuffs.

Manganese. This metal is often associated, in smaller quantity, with iron in water, and what has been said with reference to the objections of iron applies with equal or greater force to manganese. 0.02 to 0.04 part per 100,000 of manganese is likely to cause complaint, and necessitate treatment of the water for its removal. There is no evidence to suggest, however, that this or even much larger amounts of manganese have any detrimental effect on health. Manganese is, in fact, consumed in appreciably larger quantities in many common foodstuffs, and it is one of the essential elements of the animal organism.

Lead. Some time ago we were consulted about cases of cattle poisoning by water containing lead, and about the results of an inquest where the jury had returned a verdict of "died from lead poisoning" due to the action of the drinking water upon the lead pipes. In the former case we found the river water practically free from lead, but on the bottom of the stream was an easily disturbed deposit which contained large quantities of lead. In the latter case we found the moorland water alleged to be at fault had practically no action on lead, and that the child had before death exhibited all the symptoms of acute food poisoning. The jury had been led to their verdict by the fact that the analyst to whom the stomach had been sent for analysis could find nothing but minute traces of lead and copper. We also had occasion at that time to examine a natural water which, as drawn from the spring, contained about 1 part of lead in 25 millions, but in which, after filtration, no lead could be detected. A Bill which was before Parliament was likely to be opposed on this account. In consequence, the question of the amount of lead which would render water unsafe for domestic use received a good deal of attention, and our conclusions were embodied in an article contributed to the *Medical Officer*, November 3rd, 1917, which is here quoted with slight amendments. The opposition to the Bill was withdrawn.

It is not generally known that certain natural waters contain traces of lead in solution. So far as our experience extends, these waters are always derived from the mountain limestone, and in neighbourhoods where veins of galena are met with. The amount varies apparently between 1 part in $12\frac{1}{2}$ millions and 1 part in 25 millions, or between $\frac{1}{125}$ and $\frac{1}{3125}$ grain per gallon of water.

On occasions an answer may be required to the question whether water of this character could with safety be utilised for the purposes of a public supply. Such waters are usually hard (nearly all temporary) and have no action upon lead pipes, or not more than that of the water supplied to the Metropolis. There is no question, therefore, of lead being present in varying quantities, and all references found in text-books appear to apply to soft waters acting upon lead and to the maximum amount of lead permissible in waters which have passed through lead service pipes.

The following quotations from text-books show great differences of opinion :—

F. J. Smith ("Toxicology") says : "If there be only a small fraction of a grain taken in daily, this will in time lead to severe symptoms."

Davis ("Handbook of Hygiene") says : "The quantity of lead which may exert poisonous effects has been variously stated as from $\frac{1}{100}$ grain (Angus Smith) to $\frac{1}{10}$ grain per gallon. Probably one-twentieth should be regarded as possibly poisonous to most people, whilst some persons would be affected by much less."

Attfeld ("General Chemistry") says : "Hygienists regard $\frac{1}{10}$ grain of lead per gallon as dangerous, whilst a smaller quantity may do harm. Water commonly used for drinking purposes should not contain a trace."

Kenwood ("Public Health Laboratory Work") says : "In the case of lead, $\frac{1}{10}$ grain per gallon is accepted as the limit by some authorities ; but in the case of a poisonous metal which is cumulative in its action, the smallest possible trace should theoretically be considered sufficient to render condemnation of the water justifiable."

Sir T. Oliver ("Allbutt's System of Medicine") says : "Experience shows that if lead be introduced into the system in small quantities, and for a long time, it is more likely to cause serious symptoms than when it is taken in larger doses, and only on a few occasions. Cases illustrating the poisonous doses of lead are quoted by Dr. de Chaumont (in which the water contained $\frac{1}{10}$ grain per gallon) ; Dr. Hunter, of Pudsey ($\frac{1}{10}$ to $\frac{1}{20}$ grain) ; Dr. Angus Smith ($\frac{1}{100}$ grain) ; Dr. Adams ($\frac{1}{100}$ grain) ; Dr. Sidney Ringer ($\frac{1}{100}$ grain). In one of Dr. Dixon Mann's cases the drinking water contained 2.4 milligrammes of lead per litre, and in one of my own cases serious symptoms arose from drinking water which contained 0.0028 grain of lead per gallon."

Taylor ("On Poisons") says : "According to Sir R. Christison all waters act more or less upon lead, and he assigns as a limit of safety for persons using a water for domestic purposes a proportion of lead not exceeding one-millionth part, or about 1 grain in 15 gallons."

Luff ("Forensic Medicine") says : "If the amount of lead carbonate does not exceed $\frac{1}{10}$ grain per gallon, then its presence in drinking water may be neglected."

Other text-books usually say that any trace of lead renders a water unfit for drinking purposes, and then proceed to describe a method of analysis which will not detect less than $\frac{1}{10}$ grain of lead per gallon. Waters which pass this test are considered to be free from lead. The word "trace" is frequently used in this sense, which is quite unjustifiable in any work of a scientific character.

From the above quotations it would be excusable for anyone reading them to conclude that a water containing $\frac{1}{100}$ part of a grain of lead per gallon (or

even $\frac{1}{300}$ part of a grain, if Sir T. Oliver's case be accepted) might be injurious to health; but there are grave reasons for doubting whether any of these statements are correct without qualification. No doubt the samples submitted to analysis only contained these small amounts of lead, but it does not follow that this was not far below the average amount found in the water. In one of the cases quoted it is known that the implicated water often contained $\frac{1}{2}$ grain of lead per gallon. We also gather that the most serious statement is based upon a single analysis, which merely represents the amount of lead found in one particular sample, and not the average. Apparently, all refer to waters which had taken up lead in passing through the service pipes, and such waters may at one time contain even less than $\frac{1}{300}$ grain per gallon, as in Sir T. Oliver's case, yet at others may contain even as much as 1 grain per gallon.

Using 3 pints of water daily for drinking purposes, a person would consume 137 gallons per annum; hence to ingest 1 grain of lead from a water containing $\frac{1}{300}$ grain per gallon, the consumer would have to drink at this rate for nine months, or for over two years if the water only contained $\frac{1}{300}$ grain per gallon. The kidneys of any individual adult or child which could not eliminate the metal at this rate would be in such a condition that the person would be unlikely to live long enough to accumulate a poisonous dose of the metal, as, on the authority of Sir W. Osler, "Lead is rapidly¹ eliminated by kidneys and skin, and children are relatively less liable and females more liable to suffer from lead poisoning than men."

Lead is, of course, also excreted in the fæces, and this is probably the most important mode of discharge from the body.

It seems in the highest degree probable that a water which, without concentration, yields no indications of the presence of lead is perfectly safe for domestic use (and the sulphuretted hydrogen test as ordinarily used may fail to detect 1 part of lead in five million of water), and no doubt analysts will continue to certify that such waters contain no trace of lead.

In the neighbourhood of lead mines, used or disused, it is not unusual for cattle to be poisoned by lead, and this is attributed to the water used. This no doubt is true, but the lead was not in solution in the water, but suspended possibly as oxycarbonate.

The sinter deposited by a Derbyshire water contains about 0.13 per cent. of lead, and the washings from old galena refuse heaps which may gain access to and be deposited in the bed of a stream may contain as much as 4 per cent. of lead. Cattle, in drinking at these streams, may easily disturb such a deposit and imbibe with the water poisonous doses of the metal. The sinter deposited by certain Derbyshire springs is very light and easily diffused through a mass of water, and a water flowing from such springs gave 1 part of lead in five millions, yet after filtration it only gave 1 part in 25 millions. Apparently, therefore, most of the lead in the original water was in a colloid condition, and to avoid any risk from such sinter, a water from a galeniferous stratum should be carefully filtered before being supplied for domestic purposes.

The difficulty in ascertaining the amount of lead which may be imbibed daily by members of a community using moorland water derived from lead service pipes is illustrated by the following results obtained from samples of water submitted by Dr. Milligan, M.O.H., Glossop, from houses in which certain of the occupants showed signs of plumbism (the samples were collected early in the day, but probably were not the first drawn off):—

0.17, 0.14, 0.045, 0.06, 1, 0.1, 0.21, and 0.06 parts per 100,000.

¹ This rapid elimination is denied by most physiologists.

Some samples were collected morning, noon, and night, with the following results in parts per 100,000 :—

Morning.				Noon.				Night.			
	0.06	.	.	.	0.035	.	.	.	0.12		
	0.06	.	.	.	0.12	.	.	.	0.21		
	0.5	.	.	.	0.06	.	.	.	0.03		
	0.6	.	.	.	0.13	.	.	.	0.35		
	0.13	.	.	.	0.05	.	.	.	0.06		
8 a.m.,	0.46	.	.	.	0.24	.	.	5 p.m.,	0.09		
8.25 a.m.,	0.10	.	.	.	—	.	.	9 p.m.,	0.3		

In ten selected houses water was collected after standing in the pipes $8\frac{1}{2}$ to $9\frac{1}{2}$ hours. The results in parts per 100,000 were :—

0.18, 0.02, 0.21, 0.14, 0.16, 0.43, 0.10, 0.40, and 0.08.

Two special samples were taken from houses in which children suffered from colic, the samples being the first drawn in the morning. The results are interesting as showing how the lead actually present may be under-estimated :—

	(1)		(2)
Lead in 100 c.c. of poured-off water	0.02	...	0.02
Lead in 100 c.c. after acidulation and shaking in the bottle	0.40	...	0.35

Morning and evening samples were taken at different levels, where the pressure varied from 170 feet to 380 feet, with conflicting results, but, other things being equal, certainly the largest amount of lead was found in the lowest-lying areas :—

Average of morning, noon and evening samples where pressure was about 110 lbs. = 0.092 parts per 100,000.

Average of same number of houses where pressure exceeded 350 lbs. = 0.17 parts per 100,000.

Taking the same main, six houses at the top of the road were compared with six at the bottom, where it was known that the houses at the top had longer service pipes than those at the bottom. The results were :—

Houses near top : Lower pressure, 0.7, 0.45, 0.47, 0.825, 0.95, 0.52
Average, 0.65 parts per 100,000.

Houses near bottom : Higher pressure, 0.5, 0.2, 0.35, 0.3, 0.74, 0.41.
Average, 0.41 parts per 100,000.

It is obvious, therefore, that the length of service pipe has far more effect than the increased pressure. These results show that it is practically impossible to estimate the actual amount of lead which may have been the cause of plumbism ; but the conclusion at which we arrived was that where the water does not at any time of the day take up more than 0.05 part per 100,000 of lead it is quite safe, as no case of plumbism occurred in such houses. Such a maximum occurring under the most stringent conditions implies that the water drawn off in the normal manner throughout the day would contain practically no

lead, and the total daily average intake of lead by the consumers would be negligible.

A difficulty arose from the great variation in the lead contents due to changes in the character of the reservoir water. It was found that the waters from different reservoirs all showed seasonal variations, sometimes being distinctly acid and plumbo-solvent, and at other times neutral and taking up much less lead.

At our suggestion, the water from one of the most dangerous reservoirs at Glossop was treated with sodium silicate, and some days later seventeen samples were collected from selected houses. In fourteen samples no lead could be detected; the remainder gave 0.03, 0.02, 0.015 parts per 100,000.

In connection with this subject it should be remembered that even hard water containing only traces of carbonates, but much carbonic acid, especially if highly nitrated, will act on lead, and many cases of plumbism have come to our knowledge due to the use of such waters. In one case a lady suffering from internal pains was sent to London for an abdominal operation, when the surgeon, examining her mouth, found a faint blue line on the gums indicative of lead poisoning. She returned home, and the drinking water was examined and found to contain an average of about $\frac{1}{10}$ grain per gallon of lead. There were three inmates, two women and a child. The other woman suffered less than the one who was recommended for operation, and the child was unaffected, but inquiries showed that, under medical orders, the latter used only distilled water. The well was sunk in sand, probably Bagshot, and after the introduction of a load of chalk the water lost its action on lead.

We have heard of cases of plumbism due to the use of "tin-washed" lead pipes, and lead has been found in water which had passed through tin-lined lead pipes. Apparently the lead diffuses into the tin, or is derived from the so-called "pure tin" used for tinning, which often contains as much as 1 per cent. of lead.

The following extract from the L.G.B. Report on "Water Supplies of England and Wales" will be of interest.

"Action on Lead. The chief danger of moorland waters is the tendency to dissolve lead, which has been found to exist in waters derived from a soil containing peat, which usually have an acid reaction. The soft, peaty water of the moors of Yorkshire and Lancashire are particularly acid. Such waters have in many cases caused serious attacks of lead poisoning among consumers of the water when delivered, without treatment, through lead pipes. The capacity of drinking waters to dissolve lead and to cause lead poisoning has frequently been investigated by the Board. In his report for the year 1890 the medical officer to the Board estimated that upwards of 600,000 persons in the West Riding of Yorkshire alone appeared to be, at one time or another, liable to lead poisoning by the drinking of water supplied in their districts. The latest special reports on the subject are those of Dr. Houston, published in 1903. In 1909 the Board obtained detailed information from local authorities in whose district water from moorland sources was supplied as to the action of the water on lead, and the steps taken to counteract such action, with particulars of any cases of lead poisoning which had occurred in

their districts as a result of drinking water from such sources. The results of this inquiry, which were published as an appendix to the Annual Report of the Board's medical officer for 1908-09, showed that most of the undertakers supplying water from moorland sources took steps to treat the water with lime or whiting to counteract the tendency to dissolve lead, while in some instances lead service pipes were prohibited. These results are confirmed by the present return, which shows that nearly all of the undertakers whose water acts on lead require galvanised iron pipes, or treat the water with soda, whiting, lime, or chalk. In several recent local Acts which authorise the abstraction of water from moorland gathering grounds, Parliament has required the insertion of a provision compelling the undertakers to treat the water so as to prevent its acting on lead before distributing it. In modern schemes of water supply from moorland sources the precaution has been taken of removing all beds of peat within the area of the reservoir; 1,000,000 cubic yards of peat have been removed from the area to be covered by the Alwyn reservoir of the Birkenhead Corporation, and 100,000 cubic yards from the Delph reservoir of the Bolton Corporation.

The fact that a water supply is derived from a peaty subsoil does not, however, necessarily make it plumbo-solvent at all times. Whitehaven Town Council obtain their water supply from Ennerdale Lake, and although the catchment area of the lake is covered with peat, it was found in the course of an investigation of an outbreak of enteric fever in Whitehaven in 1902 that water from the lake showed no plumbo-solvent tendency at that time. Consequently, Penrith Urban District Council, who derive their water supply from Haweswater, a lake twenty-four miles due east of Ennerdale Lake, with a similar catchment area, gave up treating their water with lime, and no action on lead has apparently since been observed in this water."

Lead is foreign to the human body, is cumulative, and the intake which can be regarded as safe for all sections of the community cannot be definitely stated.

In the United States of America a limit for lead in drinking water of 0.01 parts per 100,000 has been recommended.

In view of the possibility that an exceedingly small habitual intake of lead in drinking water may cause symptoms in certain hypersensitive individuals, who form a small minority of the community, this limit would seem advisable.

The action of water on lead with special reference to the supply of drinking water is the subject of Technical Paper, No. 4, (1933) Water Pollution Research, Department of Scientific and Industrial Research. This Report is a summary of existing knowledge on this subject, and should be consulted by all who are interested in water and water supplies.

Copper. This is rarely present in natural waters, but traces (about 1 part in 100 millions) are occasionally found in moorland waters in this country.

More often the copper that is found in samples of water is derived from pipes, calorifiers, etc., through which the water has passed.

Practically all waters take up traces of copper if allowed to stand sufficiently long in contact with that metal, but under ordinary circumstances the amount taken up is negligible, and far too small to endanger health.

Acid waters are apt to act to a greater degree on copper, but the action in these cases is less marked than on iron and lead.

The action may be manifested only in the hot, so that the water in the presence of an alkaline soap becomes green in colour, and stains sponges, brushes, baths, etc. This is a frequent complaint in cases where the water supply has an action on copper.

Before passage through copper pipes, etc., acid waters should be treated to remove the acidity.

Copper is not a cumulative poison like lead, and there is no evidence that cases of ill-health or poisoning have ever arisen from the consumption of copper in water.

Provided the amount of copper in the supply does not exceed $\frac{1}{10}$ grain per gallon (0.14 part per 100,000), we are of opinion that the water can be considered as perfectly wholesome.

The use of copper pipes for water-carrying purposes has greatly extended in recent years, and experience has shown that the results are generally satisfactory provided the quality of the pipe is good and complies with the specification of the British Engineering Standards Association.

Arsenic. We have found traces of arsenic in several samples of water. Two came from wells sunk in gardens where arsenical weed-killer had been used on the paths, and another from a disused mine shaft in Cornwall. Many natural waters are known to be arsenical, but this poison is never sought for in an ordinary analysis. Tests would only be applied if there were reasons to suspect its presence, and a detectable trace would condemn any water as being unfit for drinking purposes. Probably a detectable trace, in this case, may be safely taken as 1 in 10 millions.

Objectionable Bacteria. Since the discovery of bacteria and of methods of identifying different groups, it has been found that by far the most dangerous constituents of potable water are these low forms of life. The bacteriological examination of a potable water is therefore of far greater importance from the public health point of view than a chemical analysis. Almost all the diseases definitely known to be conveyed by water in this country are diarrhoeal in character—diarrhoea, dysentery, typhoid and allied fevers, and cholera. Now that a large number of other diseases are known to be due to bacterial infection, it is quite possible that time will show that some of these diseases may be conveyed by bacteria in the drinking water. All bacteria capable of growing in the human body grow most luxuriantly at blood heat, and therefore under entirely different conditions from those which obtain in potable waters or waters which are capable of being made potable. Consequently their life in water is short, but the exact period is uncertain and liable to considerable variation according to the particular circumstances.

When outbreaks of water-borne enteric fever have occurred the most diligent search has almost invariably failed to detect the presence of the offending organism in the water. So far as we know, any outbreak of enteric fever, when its origin has been traced, has been due to excretal matter of recent origin from the human body. Excrement of animals

may give rise to serious outbreaks of diarrhoea, but not to enteric fever.

Pathogenic bacteria derived from the human or animal body appear to be more easily destroyed than ordinary water bacteria; hence if a water has been so treated as to destroy the more resistant bacteria, the inference is that all the disease-causing bacteria will also have been destroyed.

In samples of sewage or manure coliform bacteria predominate in number over all other bacteria, and, in river waters, it is fairly obvious that, under ordinary circumstances, *B. coli* will always be present.

These premises being granted, two important points are proved:—

1. That a natural water containing no *B. coli*, especially if *Cl. welchii* and streptococci are absent, cannot contain any dangerous number of disease-producing bacteria.

2. That a polluted water which has been so treated as to destroy all these organisms is as incapable of producing disease as the purest natural water.

Unfortunately, there are no means of distinguishing between the *B. coli* derived from human sewage and the *B. coli* derived from animals, birds or fishes. Therefore, it is quite possible to have present in water *B. coli* not derived from a human source.

Whilst the chemist may be able to detect objectionable inorganic substances and estimate the amount present, and thus enable a fair inference to be drawn with reference to the wholesomeness or otherwise of a water from his point of view, the bacteriologist can usually only say whether the water shows signs of excretal pollution or not, and he may be unable to say definitely that a water is unwholesome. He can, however, point out danger, and to some extent the degree of danger, far more certainly than can the chemist by the most careful analysis. No examination of a water can be complete which does not at least include a search for *B. coli* and an approximate estimation of the number present.

From a legal point of view it is questionable whether the presence of *B. coli* and other excretal bacteria is proof that a water is not wholesome, or that it is "so polluted as to be injurious to health," yet it does indicate danger, and it is usually accepted as evidence that, although at any particular time the water may not be capable of causing injury to health, at some time it will with certainty be injurious. Since prevention of such injury is the sole reason for all our sanitary legislation, such a water is always considered not only impure, about which there can be no doubt, but also not wholesome.

If a water contains few *B. coli*, but no other excretal bacteria, in, say, 100 c.c., all other factors, chemical and physical, should be considered and an examination of its source should be made before any definite opinion is expressed.

There is no doubt that some cases of typhoid fever have been attributed to water when the infection has really been conveyed by milk, shell-fish or other foods, but the possibility that water has played a part, either directly or indirectly, should always be kept in mind.

Whether goitre is capable of being caused by water is very doubtful. As has already been stated, it is regarded by some as a deficiency disease (the requisite element being iodine), but there are still some who regard it as being caused by some constituent of waters. At first it was regarded as something of mineral origin; then bacteria were suspected, with the possibility that these may be so small as to be beyond the reach of vision aided by the most powerful microscope, and capable of passing through the finest filters.

Certain other diseases may be conveyed by the water of swimming baths, bathing pools, etc., but these have attracted little attention in this country, and until recent years the only diseases suspected of having been contracted in this way were diarrhoea and typhoid fever.

In 1921, Dr. Lloyd¹ stated that several cases of otitis media had been received in the Camberwell Infirmary, the patients having visited the public swimming baths, and Dr. D. Mackenzie, who had previously directed attention to this matter, said: "My indictment does not stop at the ear—I have seen a case of suppuration of the maxillary antrums in a schoolboy, which the parents ascribed to the same cause, and . . . some time ago Mr. Hope brought before the Laryngological Section of the Royal Society of Medicine several cases of nasal sinus suppuration which he attributed to infection received during bathing." Mr. A. H. Cheatle subsequently stated: "Aural surgeons for a long time have recognised the 'bathing ear,' and that the infection passes the Eustachian tube to the middle ear from the naso-pharynx. . . . It may also enter the nasal accessory sinuses."

Much attention has now been directed to the sanitation of swimming pools, and not only have cases of typhoid, dysentery, and other affections of the alimentary canal been recorded, but also of pneumonia, tonsillitis, conjunctivitis and other affections of the eyes, as well as diseases of the ear and of the skin.

All the diseases above referred to are of bacterial origin, and doubtless are introduced from the excretions of other bathers.

If an impure water is used for bathing wounds, it is well known that erysipelas or some purulent infection frequently follows.

Having the requisite knowledge of the source from which a water is derived, and of the treatment (if any) to which it has been submitted, and adequate analyses having been made, one can usually decide to which of the following groups the water belongs:—

1. Unwholesome waters, or waters derived from such a dangerous source that at any time they may become unwholesome. These waters at times are very pleasing in appearance, and a particular sample may appear to have all the characteristics of a pure and wholesome water. Usually, however, vegetable *débris* and animalculæ are found in suspension, or excessive amounts of chloride, nitrate, or organic matter are present in solution. The bacteriological results may also be unsatisfactory, *B. coli* being found in relative abundance.

2. Wholesome waters not definitely "pure." These are waters

¹ *The Lancet*, October 8th.

derived from safe sources, but which may be discoloured by peat or slightly turbid from the presence of iron salts, or which may contain traces of zinc or other foreign matter, but in so small a quantity as not to endanger health.

3. Pure and wholesome waters. These are waters which are free from odour, colour or taste, which contain no visible suspended matter, no excess of saline or organic matter, few bacteria and no *B. coli* in 100 c.c. The source of the water should be satisfactory, or the water must have been submitted to a reliable process of purification.

4. Pure and wholesome waters "fitted for all the purposes of a public supply." These are waters fulfilling all the conditions of group 3, but which are also moderately soft and free from any acid save carbonic, and from any excess of this acid, or from any other constituent capable of causing the water to act upon lead, zinc or iron; in other words, the water must not have any appreciable action upon the materials of which mains, service pipes, and fittings are made.

Where it is impossible to classify any particular sample, further specimens should be collected for examination under varied climatic conditions.

The importance of having public supplies examined at frequent intervals and under different seasonal conditions, especially during prolonged droughts and after heavy rainfalls, cannot be over-emphasised. The variations in the different constituents can then be recorded, and afterwards any abnormality is readily detected. The seasonal variation in some supplies is very marked; in others, season has no appreciable effect. The information obtained from "charting" such results is of the greatest service in interpreting the results of analyses, and such records have, in some cases, prevented a supply being condemned, and in others, afforded the earliest indication of the supply having become contaminated.

Before proceeding to discuss the results obtainable by the various methods of analysis, let us again assert the paramount importance of the inspection of the source of supply, both in detecting possible sources of pollution and in enabling correct inferences to be drawn from the results of the chemical, bacteriological, and microscopical examinations.

Frequently it is quite unnecessary to make a detailed and complete examination of a sample of water, and before describing the various processes involved in such an examination, it is desirable first to consider what information is obtainable by each of such processes. It is only when this is known that the analyst is in a position to decide what processes to adopt in any particular case, and to interpret correctly the results of his examination. These various processes may be divided into four groups, viz., physical, microscopical and biological, chemical, and bacteriological, and we propose to consider them in this order.

CHAPTER IX

SUITABILITY OF WATER FOR TRADE PURPOSES

In the majority of cases a bacteriological examination of the water to be used for trade purposes is not necessary, the saline constituents being the important factor. Where, however, water is to be used in the manufacture of any article of food or drink, or in dairies or margarine factories, bacterial purity is essential and the quantity of saline constituents becomes of secondary importance. In such cases, for instance, a water which is excessively hard or which contains an amount of salt perceptible to the taste, may be used if it is bacteriologically pure.

It is always desirable to make certain that a source to be utilised yields a water which varies little in character; failing this, the extent of the variation should be known and the causes ascertained. Arrangements may thus be made for forecasting these changes or for detecting them quickly, and, if possible, for neutralising their effects. In dye-works, for example, waters of different characters may have to be used, yet the admixture must have a constant pH value. In such a case a chemist must be available to add acid or alkali to obtain constant results. Or, again, waters may be derived from the chalk near a tidal river, and the hardness and salinity may vary with the season and the extent of the pumping. For example, water from a certain area is derived from the chalk at about sea-level, and is used for quite a number of manufacturing purposes. When the water-level is high, the Cl may be 2.5 parts per 100,000 and the hardness 20, yet we have known this water so depressed in level that the Cl was 7 to 8, and the hardness over 40 parts per 100,000. To obtain anything like uniformity certain of the factories have had to instal softening apparatus.

Water used for the preparation of ice must be free from colour and suspended matter and contain no metallic impurities, such as iron and manganese. The presence of these substances leads to discoloration and opacity in the ice. The saline matter contained in solution should be low, and the water should be of the high degree of organic and bacterial purity expected of drinking water.

The freezing of water does not kill bacteria, and may even prolong their existence.

The samples most frequently submitted are for the purposes of ascertaining if the water is usable for steam raising. For this purpose a water should be free from sedimentary matter, contain little free carbonic acid, and the smaller the amount of salts in solution the better, especially those likely to be thrown out of solution by heat or concentration. A complete examination of the saline constituents is necessary if these exceed, say, 15 parts per 100,000, or if the electric conductivity exceeds 150.

The pH value should not be less than 6.5; below this there is an appreciable amount of carbonic or other acid present, and these would require neutralising with alkali to make the water suitable, that is, to prevent corrosion by acid steam.

Calcium carbonate is held in solution by carbonic acid, and this is more or less rapidly given off when the water is boiled. If the amount of carbonate does not exceed 9 to 10 parts per 100,000, the insoluble carbonate deposited has little tendency to form scale, but forms a mud which can be blown down. The same applies to magnesium carbonate.

Calcium sulphate does not deposit until the water is concentrated; it then crystallises out on the boiler plates as a scale, which is often hard to remove. This scale prevents the free interchange of heat between the furnace and the water, and hence causes waste of fuel. As the scale thickens, the plate may get greatly overheated and become distorted, when the consequences may be serious. Magnesium sulphate, being far more soluble, does not form scale, but unless the concentrated water is blown down sufficiently frequently it may be deposited, and the general impression is that all soluble sulphates are objectionable if present in unusual quantities.

Calcium and magnesium chlorides are most objectionable, since concentrated solutions when boiled give off hydrochloric acid in the steam which pits, and may perforate, the boiler plates at and above the water-level.

All these salts can be removed by softening with lime and soda ash, salts of sodium replacing the calcium and magnesium salts. These, being very soluble, become highly concentrated in the boiler, and if not blown down regularly they may form deposits which are more or less objectionable, hence a highly sulphated water which has been softened either by zeolites or caustic soda is not an ideal water for steam raising.

Salt (sodium chloride) does not appear to give off acid, but it has an erosive effect on brass fittings, although it does not attack the boiler plates.

Silicates in water are also held to be objectionable, since silica is generally found in considerable quantities in the hardest kind of boiler scale.

Nitrates are undesirable constituents of feed waters, since these are reduced by the iron of the boiler plates and ammonia is given off with the steam.

Where the total hardness does not exceed 10 parts per 100,000 and is chiefly due to calcium and magnesium carbonates, softening may not be necessary, but for such waters "boiler compositions" are largely used. These usually consist of soda ash, sodium phosphates or vegetable matter containing large quantities of tannic acid or similar bodies, and they cause the deposition of solid matter in the form of mud, which can be removed by blowing down.

For further information on these subjects consult J. H. Paul's "Boiler Chemistry," or Anderson's "Boiler Feed Water."

For making paper of good class, the water must be free from colour and sedimentary matter, and from every trace of iron and manganese. The salts present should not be in such quantity that any appreciable amount will deposit in the drying paper; in other words, the saline constituents should not be excessive in amount. For coarse brown papers almost any kind of water may be used. Traces of oils or fats are objectionable in all cases, since each speck in the finished paper forms a semitransparent spot.

In the manufacture of artificial silk a clear and bright water absolutely free from colour is required. The water should also be soft, and contain only a small amount of saline constituents in solution. The degree of alkalinity of the water is of great importance, but this is readily adjusted during the softening process which is usually employed in artificial silk factories.

For tanning purposes the water must be quite free from iron, and the smaller the amount of lime salts the better, since these form insoluble compounds with the tannins so largely used. Waters containing much carbonate are objectionable even in the preliminary washing of the hides, since these have usually been soaked in lime, and calcium carbonate may be deposited in the skin; moreover, the washing process is retarded.

For dyeing purposes the quality of the water becomes of the greatest importance when delicate tints are to be produced. Freedom from iron is absolutely essential, and the smaller the quantity of the saline constituents the better. The water should also be quite free from colour and turbidity.

The manufacture of photographic films requires an ample supply of good water which must be colourless and absolutely free from suspended matter and metals, such as iron, zinc and manganese, which readily give rise to deposit.

For brewing purposes the best water for producing one class of malt liquor may not be the best for another. The most varied types of water are used, but there is no doubt that the reputation of many brewers depends upon the character of their water supply. Waters hard from the presence of calcium sulphate, and containing 2 or 3 grains per gallon of magnesium as carbonate or sulphate, are especially adapted for brewing pale ales, but magnesium chloride is an objectionable constituent of a water used for this purpose. Soft water, on the other hand, is preferable for brewing dark ales, stout, and porter. Freedom from colour, turbidity, and traces of iron is also necessary. An excess of sodium chloride is said to be objectionable, but good ale is brewed with water containing some 70 parts per 100,000 of salt. For aerated bottled or table waters, good organic and bacterial purity is essential, and whilst a hard water may be used for making soda water, a soft water is preferable for making sweetened drinks. A water hard from the presence of calcium sulphate is believed to make the most palatable soda water.

Water used for the manufacture of vinegar should be clear and

bright, of good organic and bacterial purity, and free from low forms of life. It should be odourless and tasteless, and contain no excess of salts in solution nor metals, such as iron. In other words, its character should be that of a good potable water. The water should preferably be soft, and comparatively free from chalk and gypsum.

Impure water, as from rivers, should not be employed and the use of such water may be the origin of the small worms, *e.g.*, vinegar eels, which are sometimes found in vinegar factories.

For laundry purposes the water must be clear, free from iron, and soft. These conditions being complied with, others are of little importance.

Enormous amounts of water are used for cooling purposes, especially at electric power stations. At many waterworks where steam pumps are employed a portion of the water pumped is passed through the condenser. It would appear to traverse this in a very few minutes, but we have found the water therefrom to contain many more bacteria than the water at the inlet. Presumably the bacteria multiply rapidly in the slime which forms on the inner surface, and some are carried forward with the water. A single electric power station may require many millions of gallons per day for cooling purposes, and where possible river water is used. In one case, the whole flow of a river is said to pass two or three times through the condensers before it is allowed to pass the works. Where the river water is impure and turbid, the condensing surfaces become so covered with slime that the rapid interchange of heat is seriously affected. This can be minimised if the water is chlorinated. The introduction of chlorination has resulted in great economy, since the condensers require less frequent cleaning, and cooling is more efficient.

Where river water is not available or not in sufficient amount, the water which has passed through the condenser is cooled in "towers" and recirculated. These are not only expensive to construct, but the cost of pumping is considerable, and occasionally such towers become infected with bacteria which cause the tiles or other cooling surfaces to become thickly coated with a slimy growth which may become detached in masses and cause trouble.

Water used for concrete making should be reasonably clean and free from excess of sulphates and chlorides which are detrimental to the setting and solidity of the concrete.

Generally speaking, the water best adapted for domestic purposes and for a public supply will be the most suitable for such manufacturers as require a good water. Almost invariably a factory requiring a large supply has its own source, yielding water at much less cost than that from the mains, and usually has on its staff a trained chemist who has studied the particular trade and is well acquainted with the character of the water required for use in the various processes of manufacture. Moreover, there are now connected with every important branch of industry experts whose advice is always available.

PART IV

INTERPRETATION OF THE RESULTS OF PHYSICAL BIOLOGICAL AND CHEMICAL EXAMINATIONS

CHAPTER X

INTERPRETATION OF RESULTS OF PHYSICAL EXAMINATIONS

BEFORE going into details of the methods of examination, it appears to be desirable to discuss how the results are to be interpreted. This doubtless means a little overlapping, but, whatever order is observed, this appears to be inevitable. It is certainly necessary that the person examining a water should know how to interpret his results before he commences to apply his tests ; otherwise he may waste time in obtaining results which, under the circumstances of the case, may be of no practical importance, or he may use up his samples and then find that some point of importance has not been elucidated.

Very often the physical examination necessary can be done in a few seconds and without the use of any apparatus ; in fact, beyond reporting that a water is clear and bright and free from perceptible colour or odour, no actual determination of the degree of colour or turbidity is necessary, and in their presence the extent is merely indicated by the use of some adjective such as "slight," "marked," or "excessive."

When a water is received for examination, it should first be examined by the naked eye, and if the bottle in which it is submitted is opaque or dark in colour the water should be shaken up and transferred to a bottle of colourless glass. A note should be made of any turbidity or opalescence, a search made for any low forms of animal or vegetable life of sufficient size to be visible, and if time permit the water should be allowed to stand for some hours to ascertain whether any precipitate forms. Should such occur, the character and time of formation of the precipitate should be noted. On occasions, when the water contains ferrous carbonate in solution, an increasing turbidity will be noticed. Often when the deposit is examined, organisms, such as *anguillulæ*, will be discovered which had been missed in the shaken-up sample. Also, other forms of life may have attached themselves to the side of the bottle and become more readily visible.

The stopper may then be removed and the nose applied to the mouth of the bottle to detect any odour before this is dispelled by exposure to the air.

1. **Turbidity or Clarity.** If the degree of turbidity or clarity is to

be determined, this should now be done. The exact determination is only necessary when comparative experiments are being made, and then only when the water viewed in a cylinder a foot long shows that some fine suspended matter is present. The turbidity readings in comparatively clear waters can only be taken in deep tanks or streams, and not with accuracy in a laboratory. A water which is clear and bright in a 1-foot tube may be registered as clear and bright, but if there is any slight opalescence this may be noted, and later the nature of the substance causing it may be determined. If the opalescence is due to chalk, a little acid clears it instantly; if it is due to basic carbonate of iron, both acid and heat may be required. If it does not clear when thus treated, it is probably due to the presence of fine sand or clay. Occasionally it is necessary to ascertain if simple filtration through paper will produce a bright water, since if the water proves satisfactory in other respects, it can be reported that the water would be pure and wholesome if passed through any ordinary filter. Where simple filtration leaves the water opalescent, the action of lime or of alumina sulphate, or of both, may be tried, and, if successful, the mode of treatment suggested for clarifying the water would be referred to in the report. A "brilliant" or "clear and bright" water is quite satisfactory, a dull or opalescent water is not satisfactory, whilst a distinctly turbid water is highly unsatisfactory. In many cases the visible particulate matter settles rapidly, leaving the water bright; such a deposit could, of course, be simply removed by filtration. If the amount is barely perceptible, it can be recorded as "a barely perceptible trace," larger amounts being designated "a trace," "distinct deposit," or a "marked quantity"; and if these terms do not suffice, the actual amount should be determined in degrees of a stated scale, or, better still, its weight and nature should be recorded. The most important point to decide is whether the suspended matter is due to surface contamination, such as would lead to examination of the upper portion of a well or of the surroundings of a well or spring. Usually, before an opinion can be expressed, a microscopical or biological examination is necessary.

A method which we have found satisfactory for determining clarity is a modification of that adopted by the American Public Health Association (hereafter referred to as the A.P.H.A.), and it can be converted into degrees of turbidity by the use of the table given with the description of the process. As it is the clarity which is actually determined, it seems simpler and better to record this than to refer to a table to obtain the turbidity. From either the clarity or turbidity figure the amount of the suspended matter, taken as fullers earth, can be ascertained, but when this is known, it is no more useful for comparative purposes than the clarity figure. At the Metropolitan Water Board's laboratories the turbidity was, for many years, estimated in terms of saccharated carbonate of iron. This gives a redder suspension than fullers earth, but we find the colour of the latter more comparable with that of river water generally. The photoelectric turbidimeter and

colorimeter is an improved instrument for these measurements. (*Vide* Chap. XVI).

A water from a public supply should always be free from visible floating particles, and be bright and clear even when viewed in bulk. If such is not the case, the cause should be ascertained. Waters which at one time are clear and bright, and at others dull or turbid, should always be regarded with great suspicion. If particulate matter can gain access to the source of the water, then obviously the specific organisms of disease may also be admitted. Turbidity appearing soon after rain, especially if the source is in proximity to drains, cess-pools, ditches, or manured ground, indicates serious danger of pollution, and, therefore, condemns the source of supply as unsatisfactory. In such a case the sample selected for further examination should be taken when the water is turbid. Owners of wells often express their anxiety to have a "fair" sample examined, and for this purpose collect it when the water is brightest. An analysis of such a sample may be seriously misleading, and reliance thereon has often proved disastrous. The strength of a chain is that of its weakest link, and the quality of a water supply is measured by the worst sample which can be obtained from it at any time.

Water from recently constructed wells often contains suspended mineral matters, but after use for some time such waters generally become clear, the finest particles of mineral matter in the water-bearing strata having been removed by the continuous flow of water into the well. An analysis of a water taken from a new well always requires careful consideration in order to predict correctly the character of the ultimate supply.

Waters containing traces of iron salts in solution may be perfectly bright when first drawn, yet speedily become turbid and more or less brown upon standing in contact with air, in consequence of the formation of more highly oxidised and insoluble salts. Usually such waters have become turbid before reaching the laboratory, in which case the turbidity disappears quickly on the addition of acid, and the further addition of a suitable reagent reveals the presence of iron.

At a waterworks, the filtered waters should be examined for colour and turbidity daily, or twice or thrice daily if mechanical filters are in use. By this simple test imperfect filtration can often be discovered and promptly remedied. If the persons in charge of such installations had to keep records of the results of systematic observations, it would be of advantage to the owners, whether a private company or a sanitary authority, and also to the public who consume the water. The information would also be especially valuable when complaints are being investigated and would supplement the results obtained by systematic chemical and bacteriological examinations.

Filtrability. Occasionally waterworks engineers desire to know whether water from one source will filter more or less quickly than water from another. This depends chiefly upon the quantity and character of the suspended matter, colloidal or particulate, and possibly on the

quantity and quality of the organic matter in solution. Possibly, also, it may be found that the saline matter has some slight effect. In a certain investigation we had to compare a series of waters derived from several moorland sources. From the results of the physical and chemical analyses we had no reason to suspect that one would filter better than another, but it was not a difficult matter to show that one was decidedly more filtrable than the others. We compared each with the filtrability of distilled water, and the process, to be described later, seemed to be simple and reliable and rather less troublesome than the process used by Houston,¹ from whose chart the following figures are selected.

TABLE I

Source.	No. of c.c. filtered per minute.
Tap water (taken as standard)	263
Lambeth, stored water	257
Sunbury, gravel water	243
Raw Lee water	228
New River, stored water, Stoke Newington	227
New River, stored water, Hornsey	214
East London, stored water	209
Staines, aqueduct water	172
Raw Thames water	151
Raw New River water	121
West Middlesex, No. 6 reservoir stored water	116

Where engineers have to provide slow sand filters the filtrability of the water to be treated becomes important. The subject has not received the attention it deserves, but with the greater attention now being given to other methods of purification its importance is probably diminishing.

Colour. Waterworks managers are paying increasing attention to colour estimation, and many works possess colorimeters or tintometers, and record the colour of the crude and treated water daily, as, undoubtedly, the colour is some index of the quality. In our investigations of certain river-water supplies we have found, however, that the clarity figure is a more reliable guide, corresponding much more closely to the amount of organic matter present as indicated by the oxygen absorbed and albuminoid ammonia determinations. Unless the colour in a 1-foot tube or 25-cm. tube is distinct, it is practically impossible to obtain any accurate reading either by the use of tinted glasses or coloured solutions. The readings taken by different persons or under varying conditions of daylight differ widely.

Within certain limits the estimation of the colour may be of use, but outside these limits the utility is doubtful. For all ordinary purposes, a water exhibiting no colour or the faintest green in a 1-foot tube can be called normal and reported as such. If a yellow tint is observed, it can be noted as slight, marked, or very marked, or an attempt may be made to express it in degrees of the A.P.H.A.² (Hazen

¹ Seventeenth and Eighteenth Annual Reports, Metropolitan Water Board, London.

² American Public Health Association.

scale), or on the tintometer scale. The greater the departure from normal, the more organic matter the water contains, but there is no close connection between the two.

We find the measurement chiefly useful in examining waters which have been treated to remove turbidity and colour. Water which does not exceed in colour a certain fixed standard is considered satisfactory from this point of view, but if the colour is exceeded the water is more or less unsatisfactory, according to the excess of colour. In water purification works, records made at definite intervals are most useful, and serve as a check on the reliability of the process used.

All waters, including those clarified by filtration, which are submitted for examination will exhibit some colour when examined in bulk. The purest waters exhibit a pale green-blue tint only; the less pure have a colour shading from greenish-blue to yellow and reddish-brown.

The late Lord Rayleigh, as the result of numerous experiments made with waters from all parts of the world, concluded that the natural colour of water is a pale green, and that the blue tint often observed is due to reflections from the sky. We obtained for him a softened water which in the tanks had a beautiful sky-blue colour, but in Lord Rayleigh's tubes, 15 feet long, this colour could not be discovered. Still we are convinced that the colour is not a sky reflection, for it is just as marked in the lime tanks, which are completely enclosed and only lighted with louvered boards. Moreover, at certain seasons both the water in the lime tanks and in the softening tanks becomes quite green, whether the sky above is overcast or perfectly blue and unclouded. The colour is possibly due to some substance present in a colloidal condition.

The *Transactions of the Association of Water Engineers* for 1910 contains an interesting paper on the colour of waters by Professor Kemna, which can be referred to with advantage by anyone interested in the subject.

Whilst both chemical and bacteriological examinations require time and skill, a colour test can be applied in a few minutes, and by this means it is often possible to detect a change in the character of the water which may indicate that a filter bed has become defective, that the rate of filtration wants reducing, or that some other point requires attention. As a rule, waters with a decidedly yellow colour will be found to contain appreciable traces of organic matter, and when waters from the same source, as from a river, are being regularly examined, the variations in colour often serve as indices of quality. The red-brown colour due to peat is very characteristic, and the presence of traces of iron may often be inferred from the yellowish-red tint. Any unusual colour observed would indicate the need for a special examination to ascertain the cause.

The colour of the water supplied by the various London water companies was recorded by Sir W. Crookes and Professor Dewar in their monthly report to the *Water Examiner*, under the Metropolis Act, 1871. In a note appended to the table giving the results of the colour test, they said: "The ratios show the proportion of brown to

blue in the water, the figures representing millimetres in thickness of the respective standard solutions. Thus 10 : 20 would express a colour composed of 10 mm. of brown solution superimposed on 20 mm. of blue solution." The examiner to the Metropolitan Water Board recorded similar observations, and the following table, compiled from the returns for the year 1910-11, shows that there is some general correlation between the colour and the amount of organic matter in the various London supplies. The figures are the averages for the year :—

TABLE II

Source of Water.	Colour-Burgess		Oxygen absorbed.
	Brown.	Blue.	
New River	11.0	20	.0495
East London (Lee)	17.0	20	.0839
East London (Sunbury)	18.0	20	.0784
Chelsea	21.0	20	.1011
West Middlesex	21.0	20	.1000
Lambeth	21.0	20	.1007
Grand Junction	16.0	20	.0789
Southwark and Vauxhall	19.0	20	.0919
Kent wells	0.0	20	.0079
Raw Thames water	75.0	20	.2402
Raw Lee water	82.0	20	.2464
Raw New River water	38.0	20	.0900

The next table, giving the average of the monthly examinations of two of the supplies, shows, however, that there are many exceptions to the rule that the depth of the brown tint varies with the amount of the organic impurity :—

TABLE III

PERIOD.	NEW RIVER.		EAST LONDON (R. LEE).	
	Colour. Proportion of brown to 20 blue	Oxygen absorbed.	Colour. Proportion of brown to 20 blue.	Oxygen absorbed.
Average, 1909-10	11	.0495	17	.0839
April, 1910	9	.0373	14	.0555
May	10	.0336	14	.0541
June	9	.0313	14	.0582
July	8	.0332	14	.0626
August	7	.0223	13	.0530
September	6	.0207	12	.0463
October	8	.0190	13	.0426
November	10	.0374	15	.0563
December	19	.0851	20	.0900
January, 1911	15	.0555	21	.1012
February	9	.0312	16	.0730
March	14	.0544	15	.0625

The oxygen absorbed is expressed in parts per 100,000.

With experience, fairly correct inferences, as to the quality of a water may often be drawn from an examination of its colour. The medical officer of health or sanitary inspector, making inspections of districts supplied with water from shallow wells or similar sources of supply, may be guided in his selection of samples for analysis by viewing some of the water in a deep tumbler placed on a sheet of white paper.

Those in which a yellow tint is observed are the most likely to be impure, and, therefore, to require further examination. It must not be forgotten, however, that highly-nitrated and polluted waters are often clear, bright and free from colour.

Odour. No water can be quite satisfactory as a public supply, or a domestic supply, if it possesses an odour of any kind. Even when warmed to nearly boiling point the water should have no perceptible odour. A possible exception is in the case of moorland waters containing a trace of peat, but even such a water would be objectionable if, when warmed, it had a distinct odour.

Occasionally waters are examined which are of a high degree of purity and free from any excess of saline matter, yet have a more or less decided odour of sulphuretted hydrogen. These waters occur especially in districts on the Boulder Clay, and occasionally from boreholes in the Chalk and other formations. The odour disappears quickly when the water is allowed to stand exposed to the air, and aeration provides a simple remedy. Not infrequently the odour is apparent when the sample is drawn, but has disappeared by the time it has arrived at the laboratory for examination. The offensive gas is probably produced by the reduction of sulphates. Wells yielding such waters are sometimes discarded under the impression that the water is sewage polluted.

Most water authorities receive complaints from time to time of the presence of odour in the water, and often on such occasions there is also some turbidity. This may be brought about by "dead-ends" or stagnation in the mains, or by disturbances of sedimentary matter caused by alterations in flow. Probably the most common complaint is that of an odour of tar, due to the laying of new mains. If the mains have been properly coated and matured, the odour rapidly passes off, but if the bituminous coating has not been properly dried and hardened, it may continue to affect the water for twelve months.

Apart from bituminous-coated mains, water that has passed through new iron or galvanised-iron pipes often acquires a faint odour suggestive of impure hydrogen produced by the action of zinc or iron on a dilute acid, and certain waters, if allowed to stand a few hours in an iron or galvanised-iron pipe, acquire this odour, which speedily disappears when the water is exposed to air.

The yarn used for caulking pipes occasionally imparts odour and taste to the water.

Flushing the mains is the usual remedial measure employed in these cases.

Uncovered house cisterns are a not uncommon cause of trouble to which complaints of odour can be traced. On a number of occasions we have found therein either dead animals such as rats, or a heavy collection of dirt. These tanks are often inaccessibly placed in attics, are uncovered, never cleaned out, and in the course of time become very unwholesome. Drinking water taps should be direct off the main, or the cisterns should be adequately covered and periodically cleansed.

These several points should always be investigated when complaints of odour are made by any consumer.

Apart from these comparatively minor causes of complaint, water supplies sometimes possess odours either inherent in the water or induced by the processes of purification to which it has been subjected. Water supplies obtained both from wells or surface sources, such as rivers and lakes, may be affected.

Pollution by sewage, if more than of very minute degree, invariably causes odour.

Other instances of odours in well water supplies that can be cited include:—

1. Pollution of the deep water (Chalk) by gas-works waste and leakage from gasometers.

2. Pollution of the deep water (Chalk) by trade-wastes derived from factories using soakaways for the disposal of their wastes.

3. Pollution of the deep water (Chalk) by soakage from leaking paraffin and oil storage tanks, and waste-oil sumps.

4. Infiltration of river or sea water to deep wells.

5. The access of oil to the wells from the pumps.

6. Growths of iron bacteria, or fungi, in the wells.

Surface waters from rivers, lakes, impounding reservoirs, etc., often have an odour which in some cases is very faint and in others distinct. It varies according to climatic and other circumstances and may be described as "earthy," "weedy," "decaying vegetable," "musty," etc.

Where heavy pollution by sewage or trade-wastes occur, the odour may be of a more marked and offensive character.

Apart from those due to pollution by sewage and trade wastes, the odours of surface waters are due to a large number of causes, which include:—

1. Presence of living matter, bacterial, fungal, algal and animal.

2. Death and decomposition of these various forms of life.

3. Presence of colloidal vegetable matter, earthy or clayey matter.

Various forms of life are found in all surface-waters, but not all of them impart odour, and others do so only when present in a certain density, or when in a particular stage of development or decay.

Large volumes of water may be affected, as in lakes and raw water storage reservoirs, by the development of algal growths, and the objectionable changes that may take place during storage of water are described in Chapter XXXVIII.

Many algæ have a natural odour peculiar to themselves, which may be transmitted to the water in which they grow.

A list of these organisms with their odours is given in Table IV.

Many of these forms of life contain oily compounds, analogous to essential oils, to which these odours are ascribed. Odoriferous bodies may be given off by the organisms during life, or may be released into the water only by injury to, or death of, the cells. Many of these forms of life are fragile, and movements of water brought about by

TABLE IV
ODOURS OF PARTICULAR ORGANISMS
(Whipple)¹

Group.	Organism.	Natural Odour.
Aromatic Odour	<i>Diatomaceæ</i>	
	<i>Asterionella</i> .	Aromatic—geranium—fishy
	<i>Cyclotella</i> .	Faintly aromatic
	<i>Diatoma</i> .	Faintly aromatic
	<i>Meridion</i> .	Aromatic
	<i>Tabellaria</i> .	Aromatic—geranium—fishy
	<i>Synedra</i> .	Earthy
	<i>Protozoa</i>	
	<i>Cryptomonas</i> .	Candied violets
	<i>Mallomonas</i> .	Aromatic—violets—fishy
Grassy Odour	<i>Cyanophyceæ</i>	
	<i>Anabæna</i> .	Grassy and mouldy—green-corn—nasturtium—pigpen
	<i>Aphanizomenon</i> .	Grassy—nasturtium—pigpen
	<i>Clathrocystis</i> .	Sweet, grassy
	<i>Cœlosphærium</i> .	Sweet, grassy
	<i>Cylindrospermum</i>	Grassy
	<i>Rivularia</i> .	Grassy and mouldy
	<i>Chlorophyceæ</i>	
	<i>Dictyosphærium</i>	Grassy—nasturtium—fishy
	<i>Diatomaceæ</i>	
Fishy Odour	<i>Asterionella</i> .	Slightly fishy (in large numbers)
	<i>Tabellaria</i> .	Slightly fishy (in large numbers)
	<i>Chlorophyceæ</i>	
	<i>Dictyosphærium</i>	Faintly fishy (through chlorination)
	<i>Eudorina</i> .	Faintly fishy
	<i>Pandorina</i> .	Faintly fishy
	<i>Volvox</i> .	Fishy
	<i>Protozoa</i>	
	<i>Bursaria</i> .	Irish moss—salt marsh—fishy
	<i>Ceratium</i> .	Vile stench (rusty-brown colour)
	<i>Dinobryon</i> .	Fishy, like rockweed
	<i>Glenodinium</i> .	Fishy
	<i>Mallomonas</i>	Fishy (in large numbers)
	<i>Peridinium</i> .	Fishy, like clam-shells
	<i>Synura</i> .	Ripe cucumbers—muskmelon—bitter and spicy taste
	<i>Uroglenopsis</i> .	Fishy and oily—cod-liver oil

wind, etc., may suffice for their disintegration and the escape of the odour-producing contents. In other cases, the release of the "essential oils," or the production of odour-producing bodies, may occur only at the decomposition which follows death of the organisms.

Algal odours in water vary both in character and intensity, according to the number of organisms present, their stage of development, etc. Thus, the aromatic odour of *asterionella* becomes "fishy" when the organisms are present in great abundance.

¹ "The Microscopy of Drinking Water," 1927, George C. Whipple.

Also, the water may contain a mixture of odour-producing organisms, and the character of the odour will vary according to the relative densities of the different forms of life, and may change in character and intensity almost from day to day. These odours are often difficult to describe, being unlike the odours of common objects or substances.

Odours have often been ascribed to one particular form of life whereas they were really due to other accompanying organisms which were present in smaller number and ignored, or not detected. It is not unlikely that actinomyces are often responsible for the earthy and musty odours present in the water and ascribed to other forms of life.

The decomposition of organic matter, vegetable and animal, and decay of practically all water plants, algæ and other aquatic life, will, if present in sufficient amount, give rise to the production of odours. These odours may be mouldy and just disagreeable, or highly objectionable, such as when they are due to the presence of sulphides.

Objectionable odours in water are not infrequently due to growths of the sulphur bacteria, as *beggiatoa*, or the iron-bacteria, as *crenothrix polyspora*. The decomposition of the gelatinous matter produced by some growths gives rise to an odour of a particularly offensive character.

The organisms producing odours are often first found in open reservoirs, and if the water is not very efficiently filtered they find their way into the mains, where, in the absence of light and air, many forms perish and undergo putrefactive changes. Hence the water delivered to the consumers may have a marked and objectionable odour, whereas the original water in the reservoir had little or none.

The processes of filtration and purification may effectively remove the organisms, but soluble odoriferous substances derived from them may remain in the water and give rise to complaint. The odour may, on the other hand, only become apparent on chlorination of the water.

Also, profuse growths of algæ, etc., may occur in purified water reservoirs, and thus taint the water subsequent to purification. Such reservoirs should always be efficiently covered so as to exclude light, in order to lessen the possibility of algal growth.

The presence of colloidal vegetable colouring matter in surface waters is usually accompanied by a faint flavour, mostly described as "peaty" or "vegetable." The brown-coloured peaty moorland waters are typical of this class, and, curiously, consumers accustomed to this kind of water often prefer it, on account of its flavour, to other supplies, which are colourless, odourless and tasteless.

A faint earthy odour may be due to mineral matter, such as clay or sand, present in a fine state of division, and such odours are sometimes observed in the first filtrates through new or freshly washed sand filters, and in the water from newly constructed wells and reservoirs. In these cases it passes off in course of time. Earthy odours possessed by river waters often tend to become accentuated in times of flood. The presence of fine siliceous and clayey matter is often, however, not the sole or even the main cause of an earthy odour, and the most thorough filtration and purification may fail to remove it completely.

As previously mentioned such odour may be due to many causes, which include both animate and inanimate matter.

Odours Induced or Accentuated by Treatment of Water. Mention has already been made of various ways by which the water delivered to the consumers has acquired an odour which was not apparent, or present to less degree, in the water before purification.

Usually, however, the waterworks purification processes of aeration, coagulation, sedimentation and filtration remove or reduce odours, but the addition of lime or soda ash has sometimes been observed to bring about the reverse effect.

Also, odour may be added to water by its passage through filters in which washing has been unduly delayed. In these cases other unsatisfactory features in the filtrates will also be noted.

A similar effect is sometimes observed by the use of wood-wool or cloths for the removal of the suspension in lime-softened water and is due to biological growths.

Chlorination is the most important cause of odours produced during purification of water, but happily, owing to experience and improvements in its use, complaints are now much less frequent than formerly. The addition of an excessive dose of chlorine was, in the early days of chlorination, a common error, and resulted in the production of a "chlorinous" odour and taste in the water, which proved very objectionable to most consumers.

Such a condition is readily avoided, and seldom arises at the present time, but occasionally a slight chlorinous odour is still observed even when no free chlorine can be detected in the water by the usual laboratory tests. Thus, in one case which we investigated of a chlorinated chalk-derived supply, samples collected off the mains near to the waterworks contained free chlorine but had no odour or taste, yet, at more distant points, where negative tests for free chlorine were obtained, a faint odour and taste of chlorine was detected.

In some such cases the chlorinous odour may only be detected on heating the water. It is due not to free chlorine, but to a chlorine-compound which is volatile or breaks down on heating.

The chlorinous odour acquired by water is therefore not proportional either to the dose given or to the "residual," namely, that amount of chlorine which is left after the demand of the water has been satisfied. It depends on the character of the water and the substances contained therein. Some chlorinated waters, especially those containing organic matter, may show by the ortho-tolidine test over 0.5 part per million of residual chlorine and yet have no odour. It is probable that in such cases the chlorine reaction is given by chloramines or other chlorine compounds.

The odour and taste produced by chloramines are less pronounced than those of a corresponding concentration of chlorine gas in water, and a similar result is sometimes obtained when chlorine gas is replaced by sodium hypochlorite solution.

The chlorinous odours and tastes are now the least frequent of the

odours induced by the chlorination of water. All are fortunately infrequent, but some of the commonest are those described as "iodoform," "carbolic," "medicinal," or "chemist's shop," and the taste, which is usually more pronounced on warming, is decidedly unpleasant. It is typically and readily produced when an infinitesimal trace of phenol is present in a water which is chlorinated. The flavour may not be apparent immediately after chlorination, and even a day or more may be required for its development.

Many instances of this type of odour have been observed in organically pure waters, such as those usually derived from the Chalk, which have been chlorinated with very small doses of chlorine, but they may occur in any type of water. It sometimes happens that an "iodoform" odour is caused by a small dose of chlorine and not by a larger amount. Hence the process of superchlorination and dechlorination is recommended in some cases. The determining factor seems to be the presence in the water of certain substances, of which there are many, the most important being phenols, cresols and allied bodies.

The minutest trace of these substances (1 part or less of phenol per 1,000 millions) suffices to give rise to the trouble, and the origin of these traces may be trade-wastes, washings from tarred roads, or contact with other tarred or creosoted surfaces, bituminous-coated pipes and fittings, or even the atmosphere, especially in industrial areas during wet and foggy weather.

Chlorinated water passed through a newly laid bituminous-lined pipe invariably acquires an "iodoform" odour.

The odour may be induced either by phenols and allied bodies present in the water at the time of chlorination or acquired after chlorination.

Other substances which have been recorded as causes of this odour include mineral oil, tallow, leaves and *débris* from trees and plants, also living matter, such as algæ and fungi, or their products.

Not infrequently the odour will suddenly appear in a water supply for no apparent reason, and will disappear just as suddenly. Also it is often found that the complaints come mostly from distant parts of the distributing system.

Some persons are extremely sensitive to chlorination odours, whilst others may imagine an odour, knowing that the water has been treated with chlorine.

Iodine or iodides may purposely be added to water supplies and, in the event of chlorination being also employed, an "iodoform" odour is likely to result.

There are so many substances which may on chlorination produce these odours, and the amount required is so small, that it is often difficult or impossible to explain the occurrence of odours in a water supply, or discover the cause. Fortunately, however, there are now available means of prevention and cure, of which there may be mentioned the ammonia-chlorine process, superchlorination with dechlorination, and activated carbon. The former assists but is not an absolute

preventive. The latter can be used either before chlorination for the removal of the taste-producing substances, or after chlorination for the removal of excess chlorine and post-chlorination odours.

Apart from the "chlorinous" and "iodoform" odours, chlorination has been at times held responsible for the production in water of other odours and tastes, variously described as "flat," "earthy" or "musty." The evidence in this respect is not convincing, and we have usually found in these cases that the odour was present in the water prior to chlorination, and sometimes that chlorination has actually caused improvement, although occasionally it seems to accentuate the odour.

We have suspected in several cases that the use of sulphur dioxide as a dechlorinating agent has, owing to excess, been responsible for complaints of "flatness" in water.

Our experience has been that the "earthy" and "musty" odours in chlorinated waters are associated more often with waters of poor organic quality, such as those derived from rivers, and very rarely with the purer waters obtained from wells. The "iodoform" flavours seem more likely to occur in the latter, although they also occur in the former class of waters.

All complaints of odour and taste in a water supply demand the closest attention and investigation, and careful records with regard to them should be kept by all waterworks authorities. A study of these records, showing the dates and times on which the complaints arose, the location, etc., often assists in the elucidation of the cause. Repetition can often then be avoided.

Chlorination requires careful control and supervision, and regular tests of the water for odour and taste should be conducted at the waterworks. These tests are admittedly somewhat unsatisfactory, but an experienced and sensitive "taster" can be of great value.

The detection of odour and taste in a water supply should be interpreted as indicating some defect in collection, purification or distribution, which should be sought and corrected. If the cause cannot be found and the complaint continues, some additional measure of treatment for the prevention or removal of the odour and taste from the water should be considered and applied if practicable.

Taste. A water which has an odour is usually said also to have a taste. This may sometimes be true, but more often there is no taste, and the sensation is simply the result of the odour being detected from within the mouth. What has been said in the preceding section with regard to odour refers equally to most complaints of taste in water supplies.

Taste in water may, however, be unaccompanied by odour. A bitter taste may be due to the presence of iron, manganese, alumina sulphate, or excess lime. Waters containing a large amount of sodium bicarbonate are often described as faintly "inky," or sometimes "soapy."

"Flatness" is a term which relates more to taste than to odour.

It is difficult to define and is usually applied to waters which are (1) deficient in oxygen, (2) very soft and (3) slightly warm.

"Flatness" is often remarked in river-derived water supplies, whilst hard chalk waters are usually highly esteemed on account of their palatability. Consumers who have lived in a district supplied with a hard water will complain of a taste if they change to an area with soft water, and *vice versa*. Waters from local wells and springs are often said to taste "nicer" than water from the public mains.

The palatability of a water is a matter of some importance which has received less attention than it deserves. It is not sufficient to-day to supply a clear and bright, hygienically safe water, but, in addition, it must also be pleasant to drink.

Water containing an unusual quantity of salt, whether derived from the water-bearing stratum or from infiltration of sea water, will have a brackish taste. The susceptibility of various palates to the presence of salt varies very considerably. When sea water has been infiltrating into a public water supply, some persons have detected it and complained when the amount of salt did not exceed 30 parts per 100,000; others have not noticed it until it has reached 70 or more parts per 100,000. In one instance it had to be decided whether the water from a deep well in the Chalk, on which a considerable sum of money had been expended, was suitable for a public supply. It contained 119 parts per 100,000 of sodium chloride, and the salinity was distinctly evident to most people, but some who tasted the water could not detect it. The opinion was expressed that such a water was not suitable for a public supply, and this opinion was upheld on appeal to the Local Government Board. The sequel is worth mentioning. Another site was selected in the same parish and a second bore put down. This yielded a very much more abundant supply, and the water contained approximately 69 parts per 100,000 of sodium chloride. In this instance it was known that the deep wells to the north all yielded brackish water, whereas those to the south contained much less salt. The engineer, however, had sunk the well towards the north of the parish because of the ground being higher, and therefore suitable for having the well and the service reservoir in the same curtilage. We selected the low-lying ground to the extreme south because experience had taught us that water was more freely obtainable where the Chalk was only covered by a thin bed of clay, and that the water in such localities was less likely to be saline.

We have now, however, had to modify our opinion to a certain extent with reference to such waters as the result of an enlarged experience, since we found that in certain parts of Essex the only available water is that of the character described above, but containing up to 140 parts of salt per 100,000, and is used by a considerable number of persons. A newcomer always objects to it at first, but soon becomes accustomed to its use, and apparently experiences no ill-effects. Certainly such a water should not be recommended where a better is available, but where it appears impracticable to obtain any other

water, there is no serious objection to its being utilised even as a public supply, if such is greatly needed. Consideration should, however, be given to the possible presence of fluorine in waters of this character. The salinity is due to the infiltration of sea water, but the lime and magnesia salts may have almost entirely disappeared, these bases being replaced by soda derived from the Thanet Sands. The changes which a hard water may undergo by filtration through certain minerals have already been referred to in Chapter III.

Waters containing large amounts of sulphates possess a faint bitter taste.

Probably the most palatable waters are those containing nitrates and carbonic acid, waters which may have been derived from objectionable sources, the nitrates and carbonic acid being formed by the thorough oxidation of sewage and manurial matter. Such waters also are usually colourless, bright and sparkling, and therefore may be highly esteemed. When a well yielding such a water is condemned as being liable to dangerous pollution, people will still continue to use it in preference to a supply derived from a main, which, to them, is much less palatable. The sense of taste varies very much with different individuals. As previously stated, some persons can detect the presence of 30 parts of salt per 100,000, whilst others fail to detect it when 100 parts are present. Some can detect very minute traces of iron, while others cannot taste it although there may be sufficient present to give rise to opalescence and deposit.

In selecting a source of supply, palatability should be considered and, other things being equal, the most palatable water should be selected.

Unfortunately, however, the opinion of the chemist may not be shared by the consumers, so that a guarded opinion only should be expressed.

The palatability of waters, which may not be possessed of any definite odour or be described only as "flat," appears to be improved by aeration or treatment with activated carbon, and such processes are in continuous use at some waterworks.

CHAPTER XI

INTERPRETATION OF THE RESULTS OF MICROSCOPICAL AND BIOLOGICAL EXAMINATIONS

A MICROSCOPICAL examination of a potable water should be made whenever the sample shows any signs of turbidity, or when it contains any visible suspended particles, since such an examination will reveal the nature of the suspended or deposited matter, and often assist greatly in the interpretation of the results of a chemical analysis. When a supply, usually satisfactory, suddenly develops some colour, turbidity, taste or odour, the microscope very often gives a clue to the cause.

In the examination of streams, lakes, reservoirs, ponds, etc., suspected or known to be polluted, a biological examination may assist in determining the extent to which the water is affected by the filth discharged into it. Low forms of life may be found suspended in the water or growing attached to stones, twigs, water plants, etc., or floating in masses on the surface. These must be examined to ascertain whether they are organisms which thrive only in polluted waters, and whose presence, therefore, proves contamination, or whether they are organisms which later in the season may decay and create a nuisance.

The suspended matter submitted to microscopic examination may be (a) of mineral origin, or (b) of animal or vegetable origin, and in the latter case may be living or dead. Bacteria requiring great magnifying power to render them visible, and special methods for their identification, are not included in a microscopical examination, nor in what is spoken of as a biological examination. These special methods are included under the term bacteriological examination.

A water sediment is submitted to the scrutiny of the microscope to obtain information for one or more of three purposes : (1) to detect contamination, (2) to elucidate the results of the chemical examination, and (3) to ascertain the cause of any odour, colour, or turbidity.

A public water supply, to be satisfactory, should be entirely free from visible suspended matter, living or dead. Many springs and deep wells yield water of this character, and if properly stored and distributed, the water should reach the consumers in its pristine purity. Storage in open reservoirs, or in reservoirs to which light has access, may result in vegetable or animal growths appearing, and an inadequate system of filtration may contribute both to the fauna and flora of a water. Subsoil waters, river waters, and lake waters invariably require filtration, otherwise they will be intermittently delivered in a turbid condition, owing to disturbance by heavy rains and floods or to the

growth at some particular season of low forms of vegetable or, more rarely, animal life.

The presence of visible particulate matter almost invariably indicates some defect in the water supply, and its character often indicates the nature of the defect and permits of a remedy being suggested.

As chlorophyll is produced only under the influence of light, and diatoms only grow under similar conditions, the presence of diatoms or of green algæ in well water proves that some water which has been exposed to light has gained direct access to the well, possibly along the track of the pump pipe or through some aperture near the top of the well. Often the amount so entering is too small to affect the results of a chemical analysis, and without a microscopical examination a danger of this kind may easily be overlooked.

The examination of samples of water taken at regular intervals from large reservoirs will show to what extent such water is affected at different seasons by the growth of low forms of vegetable and animal life, and may prove the necessity for the adoption of a system of filtration, for improving an existing system, or making improvements in the surroundings of the reservoir to prevent the admission of water from objectionable sources. If such waters become discoloured or acquire an odour or taste, a microscopical examination will be far more likely to reveal the cause than a chemical or bacteriological analysis.

The examination of water supplied from the mains may show that growths are taking place in the mains, probably at dead-ends, and indicate the necessity for more frequent flushing or for alteration in the connections to allow of more complete circulation. Green growths may indicate defects in the covering of service reservoirs, or of house cisterns. Where vegetable and animal *débris* is found in water from the house taps, but not from the mains, a defect in the house cistern is almost certain to exist, or there may be a slimy growth in the nozzle of the tap.

The presence of particles of mineral matter alone may indicate surface contamination, or merely the nature of the stratum yielding the water. Such particles are frequently derived from mains and pipes.

The dead organic matter is usually so disintegrated as to be beyond the power of definite identification, and it may be associated with matters of mineral origin, such as clay, chalk, fine sand, oxide of iron, etc., rendering identification still more difficult.

Digesting the deposit for some hours in dilute acetic acid often removes the ferruginous matter and reveals the growth to which it was attached.

Search should be made for substances which admit of recognition, such as epithelium, striped muscle fibre, dotted ducts of pine wood, starch granules, fibres of cotton, hemp, silk, wool and other animal hair, ova, and dead or living vegetable and animal organisms. The presence of granules of wheat, potato, rice, and similar starches, of cotton and other vegetable fibres, of wool, etc., would indicate con-

tamination with sewage or foul surface water. Hairs, scales, parts of insects, etc., may indicate the existence of an uncovered and unprotected house cistern.

In the United States of America considerable stress is laid upon the biological examination of waters, by which is meant the identification and approximate enumeration of the various low forms of animal and vegetable life (excluding the bacteria). Even an expert cannot name all the living constituents in a water sediment. Some organisms go through such strange transformations during their life history that it is requisite to be acquainted not only with the fully developed forms, but also with the various other forms assumed in the cycles of their careers. The Massachusetts State Board of Health have for years past published annual reports on the biological examination of all the public water supplies in the State. The object of these examinations, however, is not so much the detection of pollution as the study of the relation of the odours of a water to the organisms which it contains, the kinds of organisms found in water from different sources, their seasonal distribution, etc. These are all subjects of special interest in that State, where the majority of the water supplies are derived from surface sources, and often give rise to complaint on account of their turbidity, odour or taste. In this country the conditions are different, and a detailed biological examination would rarely yield results at all commensurate with the labour expended, but, even when a chemical and bacteriological examination of a potable water has been made, additional information can often be obtained from a biological examination.

The organisms of importance in the examination of water may be divided into four classes :

(a) Those which, either in the living state or in process of decay, impart an odour or taste to the water.

(b) Those which, by their presence, indicate that the water is polluted with sewage or manurial matter, or with organic waste from certain processes of manufacture, since they can thrive only in such polluted waters.

(c) Those which can live only in water of considerable purity, and whose presence, therefore, contra-indicates pollution from such sources as the above.

(d) Those which grow chiefly in water containing iron and manganese and bring about the deposition of ferric hydroxide in water mains.

The number of organisms of any real importance is comparatively small, since the majority of those found in water afford no indication as to whether it is pure or impure.

Whipple classifies the various odours which appear in potable waters as "aromatic," "grassy," and "fishy," and reference should be made to Table IV, Chapter X, where a list is given of the organisms to which these odours are attributed.

Whipple does not think that the odour-producing organisms are injurious to persons in good health, but he adds : "There is some

reason to believe that people accustomed to drinking water free from organisms may be subjected to temporary intestinal disorders when they begin to drink water rich in microscopical organisms, just as people are affected by changing from a hard to a soft water, and *vice versa*. It is possible that with young children and invalids such disorders may be more common than has been supposed."

In Massachusetts a large proportion of the surface water supplies have at some time given rise to complaint by the development of an odour. Apparently, however, few of these waters were subject to filtration, since Whipple considers that one of the most efficient remedies for such complaints is filtration. As most river and surface waters in this country are filtered before being delivered to the consumers, this may account for the comparatively few recorded instances of public supplies developing any odour.

Unpleasant odours may, however, develop in carefully filtered water. The water supplying Cheltenham was filtered, yet in the spring of 1896 the water became red and turbid, and acquired an offensive odour due to the development of a species of *Crenothrix*. It was first remarked on March 1st when the large bath at a public school was being filled. The odour was most marked in water which had been heated. When the reservoirs were inspected, the whole of the water in one was found to be brown-red in colour and turbid. The water in the other reservoirs remained quite normal throughout. A reddish deposit was found on the sand filters, and by the end of April this had accumulated to such an extent that the beds became choked. The sand scraped from the surface, when exposed in heaps, exuded a dark red semi-fluid matter with a "foul privy" odour. By the middle of May the water in the affected reservoir had acquired an olive-purple tint, which gradually changed to green, and by June 10th the water had regained its normal colour, though it still remained slightly turbid. The organisms had evidently traversed the filter bed and entered the mains. Dr. Garrett stated: "The ability of the spore cocci to reproduce themselves will account for their swarming in our reservoir, and for their reproduction in, at least, some portion of the pipes—in fact, the study of the visitation constitutes an object lesson in the ease with which a microbe may develop in the mains of a water service and pollute a water which has been carefully filtered before being turned into the pipes. There are generally certain portions of the water pipes where the chance of such a development is greater than elsewhere. I refer particularly to 'dead ends' or *culs-de-sac*, where the water is liable to become stagnant. An intermittence in the supply of any part of the service possesses a similar disadvantage, by leading to the disturbance of any growth or deposit upon the pipes, which will then be washed through the house taps." *Crenothrix* appears to develop particularly in waters containing organic matter and a trace of iron in solution, and it has given rise to trouble in many towns, both in America and on the Continent. The organism found in the Cheltenham water corresponded closely with the description of the *Crenothrix* poly-

spora given by Kuhn, but certain differences caused it to be regarded as a variety, and Dr. Garrett called it *Crenothrix polyspora* var. *Cheltoniensis*. There are, doubtless, several species of *Crenothrix*. We had to investigate complaints made with reference to the water supply to a town in East Anglia. The water was unfiltered and derived from subsoil springs, and the supply had for some time been intermittent. Complaints had been received of matter resembling pieces of raw potato together with oxide of iron coming through the house pipes. When the street hydrants were opened, a quantity of gelatinous material, in thin sheets, was washed through. When kept, it acquired an offensive odour. The growth appeared to be *Crenothrix*. We have found *Crenothrix* in several subsoil waters submitted for examination on account of their having acquired an unpleasant odour and appearance. In connection with *Crenothrix* infection, it is interesting to note that Dr. Garrett found the organism had no effect upon health. He says: "Although, for many weeks during which it was affected, the water from the Dowdeswell Reservoir continued to constitute the main supply to the town, and although there were many complaints of the odour, appearance, and unpalatability of the water, there was no evidence to prove that the organism, which was being consumed in great numbers, had any pathogenic influence."

In 1891 the water supplying Bolton (Lancs.) acquired a "fishy" odour and taste. The reservoirs were found to be swarming with a confervoid growth, to which Dr. Adams attributed the odour and taste. It proved to be the *Conferva bombycina* of Kutzig, an organism often found in ponds and ditches; but why this sudden infection of an immense volume of water should have occurred is difficult to explain. Dr. Adams regarded its growth as being fostered by the presence in the water of phosphates, derived from manure and sewage on the watershed area.

Of the organisms, other than bacteria, whose mere presence in a water indicates pollution of any definite character, there are few which occur with sufficient constancy, and in sufficient number, to render desirable a special search being made for their detection and identification. In deep and shallow well waters, and in spring waters, the occurrence of any of the low forms of animal and vegetable life, such as we are considering, indicates inadequate protection or unnecessary exposure to light. In the case of the "iron-bacteria," however, we have known several cases where growths have occurred in properly constructed and protected boreholes. It can only be surmised that the "spores" from which the infection arose gained entry during the construction of the borings. Uncovered service reservoirs are particularly liable to algoid growths, and all kinds of minute animals may gain access. Covered tanks, if lighted, are also likely to become infected with green algæ, but this can be minimised by the use of red window glass. Uncovered house cisterns may become the repository of all kinds of filth. Some years ago we had to investigate the water supply to a private house, which had in a few days acquired an opalescent

appearance and a disagreeable odour and taste. As the supply came from the public mains, and was known to be satisfactory, an examination of the cistern was made. This was found to contain a piece of pork (about 1 lb.), a quantity of bread, remains of a packet of dry soap, and pieces of wallpaper. These must have been wilfully placed in the cistern by one of the servants. In several cases where complaints of odour or suspended matter in the water were made, dead rats or birds have been found in the cisterns.

In another instance, where the public water supply was above suspicion, the water from the house tap contained particulate matter and a large number of bacteria, including coliform bacteria. When the large tap from which the water was obtained, was examined, a quantity of slimy matter, resembling boiled sago, was found. It was a mass of zooglœa, and to this we attributed the contamination of the water, since after the tap had been cleansed and flamed, the water no longer contained coliform bacteria or an excessive number of bacteria, and was free from particulate matter.

Sewage Fungus

The following organisms should be sought in streams into which sewage or trade effluents discharge. The first four are all forms of what is popularly called the sewage fungus, because they are confounded with each other very frequently. All five are liable to occur in sewage farm and bacteria-bed effluents, and in streams receiving sewage or organic trade-waste :—

Sphærotilus natans.
Leptomitius lacteus.
Beggiatoa alba.
Carchesium Lachmanni.
Oscillaria.

The *Sphærotilus natans*, *Leptomitius lacteus*, *Carchesium Lachmanni* and *Beggiatoa alba* form tufts of filaments, like bits of cotton wool, though often coloured, adhering to stones, twigs, water plants, *débris*, etc., in running water. They are not found in crude sewage, as their growth requires that the water should be aerated. The resemblance is too close for any but a trained observer to distinguish between them by naked-eye examination.

The *Sphærotilus natans* flourishes best in waters polluted with the discharges from breweries, sugar refineries, beet-sugar factories, starch works, tanneries, and sewage works. It is most abundant during the winter months, and its presence indicates pollution.

The *Leptomitius lacteus* will not flourish in very impure water, but may grow luxuriantly in good sewage effluents. The *Carchesium Lachmanni* is a member of the animal kingdom, and has been little studied in this country. Dr. Mez refers to it in some detail as being especially characteristic of sewage pollution. It is closely allied to the *Vorticellæ*, and has, apparently, hitherto been generally confounded therewith. Although chiefly prevalent during the colder months, it

is also found in the summer months. Its presence does not necessarily imply a high degree of pollution, but the probability of serious contamination is accentuated if it is found associated with *Leptomitrus* or *Sphaerotilus* in the colder months, or with *Beggiatoa* or *Oscillaria* in the warmer season. It rapidly dies when removed from its natural habitat, and, as it is much more difficult to recognise when all its movements have ceased than when living, it should be searched for within a few hours of collection of the specimens.

***Beggiatoa alba*.** This fungus, which coats the bottoms of streams, etc., with a white or greyish velvety covering, is usually found in stagnant or slowly moving water containing sulphuretted hydrogen, but it is frequently found in other polluted waters, even in well waters, and in "sulphur" springs.

The *Beggiatoa* have been especially studied by Winogradsky, Cohn, and Ellis. Many different species have been described, all of which contain sulphur. In some instances this element may form 90 per cent. of the total weight of the dried organism. Winogradsky is of opinion that the sulphur is derived from the sulphuretted hydrogen found in the water, and that the *Beggiatoa* do not produce this substance. Certain it is that the *Beggiatoa* are usually found in water containing sulphuretted hydrogen, and if this gas is present it appears to be immaterial whether the water contains organic impurities or not. Thus the growth is found in the water from natural sulphur springs, as well as from sewage-polluted streams. Save in the natural sulphur springs, and occasionally in well and borehole waters, sulphuretted hydrogen is chiefly found in the waters of marshes, polluted streams, and in stagnant shallow bogs, such as are found on the Danish Zealand coast and the Limanes, along the coast of the Black Sea. In all the latter cases it seems probable that the sulphuretted hydrogen results from the decomposition of organic matter and sulphates by bacteria. Hoppe-Seyler believed that bacteria decompose cellulose with the formation of marsh gas, and that the nascent gas, acting upon calcium sulphate, gives rise to calcium carbonate, sulphuretted hydrogen, and water.

The *Beggiatoa* then decompose the sulphuretted hydrogen, storing up the sulphur in the free state, and afterwards oxidising it as required into sulphates. In this way the sulphur cycle is completed, as the sulphates taken up by or found in the plants are deposited in the cells in the form of complex organic compounds. Wherever the *Beggiatoa* are found, pollution of the water by organic matter undergoing putrid decomposition is to be suspected, but inasmuch as sulphuretted hydrogen may, as we have seen, be derived from other sources, the presence of this organism is not absolute proof of pollution.

Beggiatoa is a member of a group of bacteria classed together as the "Sulphur-bacteria," because sulphur plays an essential part in their metabolism. Professor Ellis, of Glasgow, has made an intimate study of these forms of life, and all interested in the subject should consult his monograph.¹

¹ "Sulphur Bacteria." Ellis, D. 1932. Longmans, Green & Co., London.

Besides thread-fungi such as *Beggiatoa* and *Thiothrix*, the sulphur-bacteria group includes bacilli, spirilla and cocci, and, whenever mud or water contains organic matter, vegetable or animal, which is undergoing putrid decomposition with the evolution of sulphuretted hydrogen, these various forms of life abound. Many of the sulphur-bacteria belong to the "Eubacteriales" (*i.e.*, they are true bacteria), and are not demonstrable in the ordinary microscopical or biological examination of water. These are described in Chapter XXVI. *Beggiatoa* and *Thiothrix*, however, are members of the "Thiobacteriales" which are distinguished by containing sulphur in the cells and by the size to which some of the forms grow.

Beggiatoa is described by Ellis as being "typically made up of long threads of cylindrical form with rounded ends, and, unless very long, these are of uniform thickness, 2-6 μ . The movement is normally slow and without undulation. Lengths of even a centimetre and more have been observed. The average length is 50-100 μ . The cells contain, under favourable conditions, an abundance of sulphur globules."

"*Motile, colourless threads, with oil-like contents, in a water containing organic matter in solution, may with certainty be referred to as Beggiatoa alba.*"

The filaments may be non-motile.

"*Beggiatoa alba* may exist in the coccus, the bacillus and the spirillum shapes, and each one of these may enter the zoogloea condition. Further, each kind may be motile or non-motile . . . there is no reason to doubt that, given the proper conditions, they develop once more into the filamentous condition."

Beggiatoa alba reproduces by fission and probably also by asexual spores.

Several other species of *Beggiatoa* have been described such as :

1. *Beggiatoa mirabilis*, a very large thread 15 to 45 μ in thickness with a sharply defined external membrane and transverse walls.

2. *Beggiatoa arachnoidea*, threads 5 to 6 μ in thickness, divided into cellular segments by transverse bands of clear protoplasm placed at regular intervals, and possessed of an anchoring organ of attachment. Forms in the mass thin chalky-white layers of the texture of a spider's web.

3. *Beggiatoa leptomitiformis*, threads 2 to 2.5 μ thick, not segmented. Forms in the mass a chalky-white covering to the objects on which it may settle.

Thiothrix closely resembles *Beggiatoa*, but differs from it in that (1) there is absence of free movement, (2) an anchoring slimy organ of attachment is present (also in *Beggiatoa arachnoidea*), and (3) formation of "conidia" at the free ends of the threads.

It is found under the same conditions as *Beggiatoa* and distinction between them, which may in fact be impossible, is generally unnecessary.

The presence of sulphur in these forms of life can be demonstrated by treating with a concentrated solution of sodium nitroprusside when the sulphur assumes a blood-red colour.

The Second Report of the Royal Commission on Sewage Disposal, published in 1902, contains a very interesting report on "The Pollution of the River Severn," by Boyce, MacConkey, Grunbaum, and Hill, which includes a section on the "Sewage Fungus." They have had opportunities of studying the various organisms included under the general name of "sewage fungus," and found in various polluted streams.

At Dewsbury, where they first observed the fungus, it occurred at the mouth of the main effluent from the sewage farm. The effluent was clear, the tufts of fungus very long and of a rusty colour from a deposit of oxide of iron. The form was subsequently identified as *Leptomitius lacteus*. At Birmingham, in the stream receiving the various effluents from the sewage works, it occurred in enormous quantities, and had to be removed by screens to prevent secondary decomposition. The discovery of the fungus in a stream near Shrewsbury led to the detection of a previously unsuspected source of pollution from a workhouse. This form proved to be *Sphærotilus natans*, which was afterwards found in the River Alt, producing characteristic tufts attached to the stones at the bottom of the river. In text-books, the sewage fungus is almost invariably referred to as being the *Beggiatoa alba*, which, it is now known, is only occasionally found in sewage effluents. Apparently this is also the experience of Professor Boyce and his colleagues, since they do not refer to it in the following paragraph which gives the results of their observations.

"Classed under the heading of 'sewage fungus' are certain distinct growths, the most highly organised of which is the *Leptomitius*, one of the *Saprolegniaceæ*, and therefore comparatively high in the scale of fungi. Next to it comes the *Sphærotilus*, which may be placed among the more highly-developed forms of bacteria. There are also several bacterial zoogloea masses, which may assume a branching appearance and simulate a sewage fungus. . . . In polluted brooks all the appearance of the typical fungus was sometimes caused by extensive growths of a protozoon, the *Carchesium Lachmanni*."

The presence of *Sphærotilus*, they found, indicated much greater pollution than the presence of *Leptomitius*, the latter only occurring in well-oxygenated and comparatively slightly polluted waters, whilst the former grows well in any oxygenated sewage effluent. The zoogloea masses referred to above are regarded as being closely allied to the *Sphærotilus*, if not identical therewith, and "flourish best where the stream of sewage is most active and thinnest." They found the *Carchesium Lachmanni* in great masses under similar conditions to those of the *Sphærotilus*, and they regard all the above low forms of life as playing no unimportant part in the process of sewage purification. They also found the *Euglena viridis* in certain field drains, and in an effluent from a coke bed upon which sewage was being treated. The *Sphærotilus* is probably most frequently confounded with *Beggiatoa* by inexperienced observers. According to our experience, the latter is chiefly found living in waters containing sulphuretted hydrogen,

whilst the former rarely, if ever, occurs in such waters. We have found *Sphærotilus* in rivers polluted by sewage, but more frequently where pollution occurs by trade-wastes from beet-sugar factories, dairies, jam works and paper mills. Masses of these organisms from time to time become detached from the stones, etc., upon which they have been growing, and, floating on the surface of a stream, enter into decomposition and give off most offensive odours.

Oscillaria. These filamentous algæ are widely distributed. They are found in all streams, whether the water be pure or impure. The non-motile forms, however, are rarely found in unclean waters, whilst a few of the motile forms are, according to Mez, very characteristic of polluted waters. The latter are nearly always black, and cover the beds of streams or the damp sloping banks. Floating organic *débris* covered with these organisms often occurs in masses on the surface of polluted streams. At certain periods these have offensive odours, and are popularly regarded as being composed of faecal matter which has escaped from drains, sewers, or sewage works. They abound in the summer or autumn, differing, therefore, in seasonal distribution from the other organisms most frequently associated with polluted streams. They are undoubtedly Nature's scavengers, preparing the way for the appearance of higher forms of vegetable and animal life.

The threads of oscillaria are straight or slightly curved, have rounded ends, colourless, grey or blue-green in colour, without branches or sheaths, and contain cells usually cylindrical in shape. They vary in thickness from 1 to 50 μ , and exhibit characteristic oscillating movements.

In the examination of streams, other definite organisms characteristic of particular kinds of pollution have occasionally to be sought, such as yeast, when contamination by brewery refuse is suspected.

Iron-Bacteria

Another group of organisms of interest to the water analyst and of particular importance to the water engineer, is that known as the "iron-bacteria."

These bacteria are usually associated with iron-containing waters, and are characterised by the presence of iron on their surfaces or in their substance. This feature is, however, also shown, but to less degree, by certain other low forms of life which include thread-fungi and algæ.

The iron-bacteria have been intimately studied by Professor Ellis of the Royal Technical College, Glasgow, and his book, "Iron Bacteria,"¹ should be consulted by all who are interested in this subject. Much of our information regarding these organisms is derived from that work.

The growth of these organisms in water leads to the accumulation of large slimy ochre-coloured deposits in tanks and pipes. This deposit consists of the remains of the bacteria and their mucilaginous sheaths in which are contained large quantities of iron in the form of ferric

¹ "Iron Bacteria." Ellis, D. 1919. Methuen & Co., Ltd., London.

hydroxide. These bacteria have the power of abstracting iron either from the water itself or from the pipes or surfaces with which they come into contact. Ferruginous waters are invariably found to contain iron-bacteria, but iron-free waters can also support their growth, and it is not uncommon to find them in water containing less than 0.01 parts per 100,000 of iron. The abstraction, oxidation and storage of iron by these growths is continuous, and hence there occurs in course of time a large accumulation of ferric hydroxide. Some of these bacteria take up manganese as readily as iron.

The presence of organic matter in a water is necessary for the proliferation of the iron-bacteria, but iron, on the other hand, is not absolutely essential. In our experience, however, they are rarely, if ever, found in water in the complete absence of iron. Carbon dioxide is favourable to their growth, and proliferation of iron-bacteria may occur in alum-solution tanks.

The development of a growth of iron-bacteria in a water supply is of importance for the following reasons :

1. Deterioration occurs in the quality of the water. Brown-coloured turbidity and deposit may be produced, and objectionable odours may result from the death of the bacteria and the decomposition of the slime. The organic matter in the water is increased and this in turn favours the multiplication of other bacteria.

2. Large deposits occur in reservoirs, tanks and pipes, and the latter may become blocked, or the flow of water through them seriously impeded. Blocking of sand filters may result from growths of iron-bacteria and the underdrains are often sites of growth.

3. They may play some part, probably a subordinate one, in the formation of tubercular incrustations in iron mains. This leads to interference with the flow of water, and destruction of the pipes.

The presence of growths of iron-bacteria in water is indicated by the appearance of slimy, ochre-coloured streamers or deposit, and is confirmed by microscopical examination.

Included in the iron-bacteria are various closely allied organisms, such as :—

1. *Leptothrix ochracea*, also known as *Chlamydothrix ochracea*.
2. *Gallionella ferruginea*, also known as *Cladothrix ferruginea*, and *Didymohelix*.
3. *Spirophyllum ferrugineum*.
4. *Crenothrix polyspora*, also known as *Crenothrix manganifera* (when it contains manganese instead of iron).
5. *Cladothrix dichotoma*, also known as *Sphaerotilus dichotoma*.
6. *Clonothrix fusca*.

A marked characteristic of the iron-bacteria is the fact that one and the same organism may assume a number of different forms (pleomorphism), and this has led to much confusion and difficulty in identification. Fortunately, however, it generally suffices for the purposes of the waterworks engineer to establish the presence of "iron-bacteria" without attempting to determine the particular species.

Often they are mixed or several forms of the same organism are seen at one and the same time.

There is some doubt, for example, whether *Leptothrix*, *Gallionella* and *Spirophyllum* are not simply different forms of the same organism. Ellis tends to this view, and suggests that the form assumed may be determined by some external condition such as light.

Leptothrix ochracea is the commonest form of iron-bacteria, and is widely distributed in ferruginous waters throughout the world. Deposits contain only the dead organisms with their iron-laden sheaths, but living growths are characterised by straight uniform homogeneous threads, $2\ \mu$ in thickness and $200\ \mu$ or more in length. The thickness is increased by iron accumulation, and the iron can be removed for the better observation of the organism by treatment with dilute hydrochloric acid. The thread has a delicate mucilaginous sheath, but shows no transverse divisions or branches and is non-motile. Microscopical examination will usually show a number of threads growing alongside one another and attached by their mucilaginous sheaths.

Multiplication takes place by (1) fragmentation, and (2) formation of spore-like bodies called conidia.

Gallionella ferruginea is often associated with *Leptothrix*, but whereas the latter predominates in exposed water, *Gallionella* is often the most prominent form in water where light is excluded, as in tunnels, mains, pipes, etc.

When treated with acid and examined microscopically, it appears as a twisted, looped homogeneous thread, and Ellis aptly describes its appearance as a hairpin twisted spirally on itself, although when mature and impregnated with iron, it may look like a string of beads. The threads are only about half as thick as, and much shorter than, those of *Leptothrix*. Multiplication is by fragmentation and also by conidia formation.

Spirophyllum ferrugineum, a form first described by Ellis, is similar to *Gallionella* and is more prominent in dark places than in exposed water. It appears as a flat band-like homogeneous structure, with square-cut ends and twisted in the form of a spiral. It may be from $1\ \mu$ to $6\ \mu$ in thickness and over $200\ \mu$ in length, and the spiral turns on a thread may be one or two or many. Multiplication takes place by fragmentation and conidia formation.

Crenothrix polyspora is widely distributed and may suddenly invade a water supply with calamitous results to the water. Cheltenham suffered an experience of this kind, and the event has already been discussed.

The growth may affect a large bulk of water and give rise to a reddish-brown discoloration, an odour, said in the Cheltenham case to be offensive, and much general deterioration of the water. Also, as shown at Cheltenham, it may permeate sand filters and appear in the filtered water.

On several occasions we have seen the whole of the water in swimming baths or reservoirs assume a reddish-brown colour and opacity due to the sudden proliferation of this organism.

It is often found in water, but multiplication is seldom so active as to give rise to marked changes in the water. The particular conditions that are required to give rise to this sudden, infrequent, and abnormal multiplication are obscure, but it could not occur in the absence of organic matter which is a necessary food material for this organism, as for others.

Crenothrix threads in water attach themselves at one end to some foreign object, such as a particle of dirt, and a rosette of threads may be attached to the same body. The microscopical appearance of a semi-mature thread has been likened by Ellis to a long test-tube filled with a single row of marbles, the test-tube representing the sheath and the marbles the contained cells. The thread may measure $5\ \mu$ in thickness and $250\ \mu$ in length. Unlike *Cladothrix* the cells are visible in the unstained specimen.

At a later stage of development, when the organisms may have attained a length of 3 millimetres, the cells at the distal end of the thread may cause distension of the containing membrane, so that the thread is no longer cylindrical but is wider at the top than at its attached end. At the free funnel-shaped end, the cells, which become spherical, are no longer in a single row, but appear as a mass. These cells become detached from the thread by the rupture of the sheath and each one can develop into a new thread.

In other cases there is no distension of the distal end of the thread, and the reproductive cells cast off from the thread are not round but elongated.

Under abnormal conditions, multiplication may be so active that a large number of daughter threads may be seen sprouting from all parts of the parent thread.

Multiplication of the detached coccoid cells may be abnormally rapid and proceed without the intervening thread formation, hence there results a condition known as zooglycea, which consists of a number of "cocci" contained inside a gelatinous or slimy mass.

These various states are seen in the examination of water which has been discoloured by *Crenothrix* growth.

Crenothrix polyspora resembles *Cladothrix dichotoma* and *Beggiatoa alba*, and is distinguished microscopically as follows:

In young threads of *Crenothrix* the cells are visible but not the sheath.

In young threads of *Cladothrix dichotoma* the sheath is visible but not the cells, until they have been stained.

Young threads of *Beggiatoa* are motile, show no transverse divisions or cellular compartments, and contain sulphur globules which appear as small black circles inside the thread. They can be "stained" red by treatment with a solution of sodium nitroprusside.

Growths of *Anthophysa vegetans*, a protozoon, may give rise to brown discoloration of water in reservoirs and streams. The brown stems of this organism may be mistaken for *Crenothrix*, but it can be distinguished from the iron-bacteria in that the colour is not due to

iron and by the presence of spherical clusters of colourless flagellate animalcules attached in some cases to the extremities of the brown stems.

Cladothrix (*Sphærotilus*) *dichotoma* closely resembles *Crenothrix polyspora* in structure, and the two are intimately related. Other very similar thread-fungi are *Sphærotilus natans*, and *Clonothrix fusca* which has been found only in Germany. *Chlamydothrix sideroporus* is a form which appears to differ from *Cladothrix dichotoma* only in forming an adhesive disc for attachment to objects in water.

Cladothrix is found growing in water of inferior organic purity, especially when stagnant, and the growth appears as a soft, slimy greyish-brown mass, loosely attached by its mucilaginous matter to some object in the water or on the sides and bottom of the stream, channel, pipe, etc.

The growth of *Cladothrix* is accompanied by a musty odour, but on the death of the fungus and decomposition of its slimy substance, a foul odour is emitted.

In ferruginous waters the growth is brown, but otherwise it may have little colour. Iron is not essential for *Cladothrix* growth.

The individual thread of *Cladothrix*, which may attain a length of 1 millimetre, appears as a uniform tubular structure composed of a sheath and transverse bands with cells in the compartments thus formed. It differs from *Crenothrix* in that (1) the funnel-shaped expansion of the distal ends of the threads of *Crenothrix* is not seen; (2) the cells form one single row; and (3) the cells can only be observed in some threads when stained, as by iodine.

In *Sphærotilus natans* the threads show little, if any, "branching," usually run parallel to one another, and are enclosed in a common mucilaginous covering.

The cells of *Cladothrix* threads are rod-shaped or oval, and measure about $2\ \mu$ in thickness and 3 to $6\ \mu$ in length. They escape from the ruptured end of the thread, and also laterally, so that apparently empty compartments may be seen along the thread. These spaces are filled by the mucilaginous material of the sheath. At a later stage the filaments may appear as hollow tubular structures containing only a few cells.

Most filaments in a mass of *Cladothrix* appear as unbranched threads, but owing to lateral adhesion of daughter to parent threads, an appearance of branching is sometimes seen.

Reproduction is by the rejuvenescence of a single cell or a group of cells, and according to Ellis there is no trace of the formation of spores by this fungus, though some workers have recorded the presence of such bodies.

Usually reproduction is by the cells which are released from the thread. These cells possess cilia, swim away and become attached to some object, and by division develop into a thread of cells.

In other cases, fragments of threads are given off by the colony, and the fragments, which may possess cilia, settle down and elongate into new filaments.

Microscopical examination of the iron-bacteria is best conducted on fresh specimens. Suspicious particles floating in the water are selected. When ferruginous deposits are examined, only the skeletons and *débris* of the threads are usually found.

The specimen should be examined in the untreated state, and again after (1) treatment with dilute hydrochloric acid which removes the iron deposited on the threads, and (2) after treatment with iodine which helps to distinguish *Cladothrix* from *Crenothrix*.

The iron present can readily be demonstrated by the blue coloration produced on the addition of hydrochloric acid and potassium ferrocyanide.

The spiral twisting of *Gallionella* and *Spirophyllum* makes their identification easy, but it is often difficult to identify some of the other members of the iron-bacteria.

The pleomorphism of the thread-fungi gives rise to confusion, and very varied microscopical appearances are seen.

It is sometimes important to distinguish iron-bacteria from sulphur-bacteria, such as *Beggiatoa*. The points of difference in the microscopical appearances have already been mentioned. *Beggiatoa* grows where oxygen is deficient and sulphuretted hydrogen available, hence it is sometimes found in water heavily polluted with sewage.

The fact that a growth in water is slimy and little discoloured has often sufficed for a diagnosis of "*Beggiatoa*," but it must be remembered that growths of iron-bacteria may be very mucilaginous, and microscopical examination should always be employed.

The iron-bacteria, whilst organic matter is necessary for their growth, cannot subsist under the conditions which are favourable to *Beggiatoa*, and hence are not found in water which is sewage-polluted or laden with sulphuretted hydrogen.

They have not therefore the same significance as *Beggiatoa*, and we have often found *Gallionella* in waters of great organic and bacterial purity.

Slight acidity in a water favours their growth, whereas alkalinity is inhibitory.

As previously indicated, the fact that a water is not ferruginous, as ordinarily understood, does not exclude growths of iron-bacteria. It appears that these organisms have a predilection for organic compounds of iron or manganese, and that after utilisation of the organic matter the iron or manganese is expelled as a waste product, but remains attached to the threads as insoluble salts. It appears unimportant to these organisms whether the organic complexes which provide their nourishment contain iron or manganese, and when the latter replaces iron the organisms can be referred to as "*manganese-bacteria*." The services of these bacteria have actually been enlisted in waterworks practice for the removal of manganese from water required for public supply purposes.

From what has been said it will be inferred that an abundance of iron-bacteria in a water indicates :

1. The presence of organic matter in the water.
2. The presence of iron or manganese in the water.

Traces of iron-bacteria (*Gallionella*) can be found in practically all specimens of deposits from iron water-mains and pipes, even when the water is of great organic purity and contains no undue trace of iron (0.02 part per 100,000). It is only in the presence of profuse growth that the above indications apply and remedial measures are necessary.

These measures, which are considered in the chapters dealing with the treatment of water, include :

1. Correction of acidity of the water.
2. Removal of suspended and organic matter from the water.
3. Removal of iron and manganese from the water.

Treatment by the addition of lime, followed by sedimentation and filtration, is often the best measure.

By far the best work in the English language on the low forms of life found in potable waters is the beautifully illustrated "The Microscopy of Drinking Water," by Professor G. C. Whipple, late Gordon McKay Professor of Engineering, Harvard University. (London: Chapman and Hall Ltd.)

CHAPTER XII

INTERPRETATION OF RESULTS OF PHYSICO-CHEMICAL EXAMINATION OF WATER

Electric Conductivity. It is a well-known fact that the electrical conductivity of any sample of water depends almost entirely upon the salts dissolved in it, and, providing the solution is very dilute, the conductivity is proportional to the amount of the substance dissolved in the water. Unfortunately, the determination of the conductivity tells us nothing as to the nature of the solids in solution, but if this increases or decreases in amount, so does the conductivity increase or decrease. If the conductivity of a water is known, any change in the mineral character of the water will be indicated by a change in the conductivity.

The turbidity, colour, etc., having been ascertained, potable water should next be submitted to an electric current and the conductivity ascertained at 20° C. The results on the instrument used, which is known as the Conductivity Meter ¹ (see p. 198), are expressed in "units," and the utility of the test is very great in laboratories where many samples of water are examined.

The unit adopted is the reciprocal of 1 megohm per centimetre-cube, and, in the apparatus as ordinarily supplied, the scale extends from zero to 2,000 units.

Where water from a particular source is being examined periodically, it is found after the examination of a few specimens, that the value of electric conductivity gives a common factor, which is useful afterwards for determining the "total solids." As the electric conductivity can be determined in a few minutes, whereas the "total solids" takes hours and requires much skill, it becomes unnecessary to make a direct determination, unless there has been a marked change in the electrical conductivity. A fraction of a milligramme change in the total solids is shown at once by the degree of conductivity, a change which would barely be perceptible by weighing.

Unfortunately, this factor varies somewhat with different types of water, ranging from 12 to 18, as shown in our routine work.

According to Kohlrausch, as quoted in Whenham's "Theory of Solution," the E.C. of certain salts is given as under :

1 mg. Na_2CO_3 in 100 c.c. pure water	= 20.2
1 " NaCl " "	= 18.4
1 " Na_2SO_4 " "	= 15
1 " MgSO_4 " "	= 18
1 " MgCl_2 " "	= 22
1 " HCl " "	= 93

¹ Supplied by Messrs. Evershed & Vignoles, Chiswick, London, W.4.

Using the apparatus previously referred to, we obtained :—

1 mg. CaSO_4 in 100 c.c. pure water	=	15.7
1 " NaHCO_3 " "	=	8.8
1 " Na_2SiO_3 " "	=	6.5
1 " CaCO_3 " "	=	18 (?)

The average value for $\frac{\text{E.C.}}{\text{T.S.}}$ of sixteen moorland waters examined was 14.4. The lowest was 8, given by a peaty water from Dartmoor, and the highest 19, from an acid water from Yorkshire.

6	gave between 12 and 13
3	" " 13 " 14
1	" " 16
3	" " 16 " 17
2	" " 17 " 18

Apparently the lower figures were given by peaty waters far removed from manufacturing districts, and the highest from the neighbourhood of manufacturing districts.

Waters of miscellaneous origin have about the same range, and the average is about 14.5. The following are given as examples :—

	Source.	E.C.	T.S.	$\frac{\text{E.C.}}{\text{T.S.}}$		Source.	E.C.	T.S.	$\frac{\text{E.C.}}{\text{T.S.}}$
1.	Thames derived .	416	30	13.9	31.	Deep Wells, N.R.S.	333	18.6	17.9
2.	" " " "	440	29.5	14.9	32.	" " " "	853	58	14.7
3.	Lee " derived " .	508	35	14.4	33.	" " " "	640	39	16.4
4.	" " " "	580	40.6	14.3	34.	" " " "	520	31	16.8
5.	River derived, Hampshire .	400	28	14.3	35.	" " " "	765	51.8	14.75
6.	River derived, Cork.	90	6.1	14.75	36.	" " " "	785	55	14.25
7-13.	Series of shallow wells in one village—				37.	Magnesian limestone	1,211	95	12.7
	Maximum .	2,994	206	14.5	38.	Springs, schist and gneiss .	287	26	11
	Minimum .	1,496	96	15.6	39.	" " " "	287	25.4	11.7
14.	Wells in chalk .	460	37	12.4	40.	" " " "	350	22	15.9
15.	" " " "	479	33	14.5	41.	" " " "	300	21	14.3
16.	" " " "	508	37	13.5	42.	" " " "	280	24	11.7
17.	" " " "	538	38	14	43.	" " " "	320	21.6	14.8
18.	" " " "	658	44.3	14.8	44.	" " " "	280	23	12.2
19.	" " " "	1,280	83	15.4	45.	" " " "	300	19.4	15.45
20.	" " " "	564	37	15.2	46.	Hastings sands .	393	28.6	13.7
21.	Wells in chalk (No. 20 softened)				47.	" " " "	113	8.2	13.8
22.	Chalk under London clay	283	23	12.3	48.	" " " "	118	6.5	18.2
23.	" " " "	1,355	112	13.9	49.	" " " "	354	26.4	13.6
24.	" " " "	1,370	135	10.2	50.	Spring water before filtration .	153	11.6	13.2
25.	" " " "	598	39.6	15.1	51.	Spring water after filtration .	153	11.8	13
26.	" " " "	1,312	83	15.8	52.	Boulder clay well .	1,436	118	12.2
27.	" " " "	954	63	15.1	53.	Well near tidal river	2,843	158	17.9
28.	" " " "	598	44	13.6					
29.	" " " "	593	40	14.8					
30.	" " " "	490	36.5	13.4					
	" " " "	561	45	12.4					

W. H. Kitto, M.Sc., in a Paper in the *Analyst*,¹ has drawn a closer correlation between the mineral content of waters and their conductivity. By graphing the conductivity of dilute solutions of the salts found in natural waters, against the known "total solid" content of these solutions, empirical curves are drawn. Since it was

¹ "A Contribution to Water Analysis." *Analyst*, March, 1938, Vol. 63, No. 744.

found that the solutions of salts of the three metals normally found in waters, *i.e.*, calcium, magnesium and sodium, have the same curve for the same anion, natural waters are classified into three types, the sulphate or nitrate, the bicarbonate or general saline, and the chloride or carbonate. This provides a means, when the mineral constituents of a water have been determined, of deducing precisely its "total solid" content. The water is allocated, from the chemically equivalent quantities of the anions present, to one or other of the curves, and, given the electrical conductivity, the "total solids" are read. Silica, being present as a non-electrolyte, is estimated and added to this result.

Summarised, the determination of the E.C. is useful for the following purposes:—

1. For ascertaining the quality of distilled water. As purchased, distilled water may have an E.C. varying from 2 to 14 or upwards, but only water with E.C. about 2 should be used in connection with water analysis. By careful distillation this can be obtained with comparative ease, providing a soft water is used. The water to be distilled should be rendered very faintly acid (*pH* 5) by addition of pure sulphuric acid to decompose all the carbonates. Then distil slowly, examining successive portions of the distillate until the E.C. falls to 2, and collect until about 90 per cent. of the water has distilled over. Water thus prepared yields no free ammonia and a barely detectable trace of carbonic acid. The avoidance of splashing is imperative, and, if the highest-class water is desired, the distillate should be collected with as little contact with air as possible.

2. For deciding upon the amount of water to be taken for various chemical determinations. Thus a water with a low E.C. indicates a water with little saline matter, and larger amounts will have to be taken for estimating the total solids, chlorides, hardness, etc., than is the case with waters having a high conductivity.

3. Where the usual determinations in a sanitary analysis have been made, the presence of such salts as sodium carbonate and sulphate may be overlooked if the total solids or the E.C. is not determined, and the latter is by far the simpler operation. The estimation of the E.C. may often render it unnecessary to determine the total solids.

4. Where waters from the same source are periodically examined, the E.C. at once tells whether there is any variation in character, as far as the dissolved solids are concerned, and indicates the extent of this variation.

5. Where it is desirable to ascertain the proportions in which certain waters are mixed, this can be done better from the values of the respective E.C.'s than from the results of any chemical tests. For example, the supply to a certain reservoir consists of water raised from a deep well with E.C. 1,200, and of water derived from springs with E.C. 450. If the water in the reservoir gives E.C. 825, it obviously consists of deep well water and spring water in equal proportions. We recently examined waters from mains in a town supplied from different

sources, and the distribution was found to be quite different from what had been surmised by the engineers.

The conductivity meter has proved indispensable to us, not only in the laboratory, but also in field work.

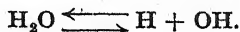
The apparatus may be used at waterworks for ascertaining whether any change has taken place in the character of a water, and thus indicate the necessity for an analysis to be made. It is employed in many factories for detecting leakage in steam condensers, for detecting priming in steam boilers, and for controlling water-softening plants. With London tap water Mr. Digby found that by adding successive quantities of lime the conductivity decreased to a minimum at the point when only permanent hardness remained, and increased again when more lime was added, that is, when the lime was in excess. He stated: "The conductance tube may serve . . . to ascertain the point at which the addition of lime should be discontinued in the Clark process of softening, as any excess of lime is made apparent by the rise in conductance."

The apparatus is not, however, particularly recommended for regulating water softening, as more reliable results are obtainable by other equally simple methods which will be described in the next section and in Chapter XX.

Reaction and Hydrogen-Ion Concentration or *pH*. The simplest explanation of "*pH*" we have seen was contained in S. W. Cole's "Practical Physiological Chemistry," 6th Edition, which may be consulted with advantage by those requiring more information than is given here. The following is quoted from the section on "The Concentration of Hydrogen Ions."

"The only satisfactory method of expressing the 'reaction' of a fluid is in terms of the concentration of hydrogen ions per litre of the fluid.

Pure distilled water is very slightly ionised into hydrogen ions or hydrions and hydroxyl ions or hydroxidions.

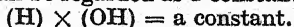


This dissociation proceeds to an equilibrium, in which, according to the laws of mass action, $\frac{(\text{H}) \times (\text{OH})}{(\text{H}_2\text{O})} = \text{a constant}.$

So, $(\text{H}) \times (\text{OH}) = \text{a constant} \times (\text{H}_2\text{O}).$

The brackets indicate the concentration per litre of gram-ions or gram-moles respectively.

Since the mass of undissociated water is enormously large compared to the mass of the free ions, it can be regarded as a constant, so



This constant varies considerably with the temperature. At 21° C. it is 10^{-14} . Since the ions are equal in number, each has a concentration of 10^{-7} gram-ions per litre.

If an acid be added to distilled water, the acid is partially or completely dissociated into hydrogen ions and the negative ions characteristic of the acid employed. In such a mixture the concentration of hydrogen ions per litre at 21° C. is greater than 10^{-7} grammes, and the solution is 'acid.'

If an alkali be added to distilled water, the base is dissociated into hydroxyl ions and certain positive ions. The concentration of hydrogen ions per

litre at 21° C. is consequently less than 10^{-7} grammes, and the solution is 'alkaline.'

A 'neutral' solution is one in which (H) at 21° C. = 10^{-7} . An 'acid' solution is one in which (H) at 21° C. is greater than 10^{-7} . An 'alkaline' solution is one in which (H) at 21° C. is less than 10^{-7} .

This method of expressing the hydrogen-ion concentration is not convenient. It is preferable to adopt the notation of Sorenson, who introduced the symbol *pH* to denote the 'hydrogen-ion-exponent.' *pH* is the logarithm to the base 10 of (H), the negative sign being omitted.

So it will be observed that *pH* decreases as the acidity increases, and *pH* increases as the liquid becomes more alkaline.

It is important to note that the *pH* of a solution cannot be determined by the ordinary method of titration. . . . Titration . . . only gives an index of the *capacity* of the solution to neutralise acids or alkalies; it does not give us information concerning the *potential* of the hydrogen ions, i.e., the *pH*."

The accurate determination of the *pH* value is an electric one, involving the use of expensive and intricate apparatus, but values sufficiently near for most purposes can be obtained by the use of "indicators," which vary in colour with the *pH* of the solution, within a range peculiar to each. Thus methyl-orange gives a red colour when the *pH* is 3.1 or under, and passes through various shades of orange to yellow at 4.4 or over. Brilliant cresyl blue gives a deep blue with liquids having a *pH* of 10.8 or under, and becomes brown when the *pH* reaches 11.6, such as when the water contains a trace of calcium hydroxide.

It is always desirable to know whether a water is acid or alkaline in reaction, and this is easily done by means of the indicators litmus and lacmoid. For comparative purposes, however, other indicators are infinitely better, since a judicious selection shows that there is no sharp line between acids and alkalies, the one fading off gradually into the other. With litmus and lacmoid this is not so clearly shown as with the hydrogen-ion indicator, and, assuming the true neutral point for water is, as we have seen, when the *pH* value is 7, then when the *pH* exceeds 7 the water is more or less alkaline, whereas when the value is less than 7 the water is more or less acid. It must be remembered, however, that this index does not represent the titratable acidity (it merely represents the hydrogen-ion concentration in the water), and that mineral acids ionise to a greater extent than organic acids. Thus the *pH* of N 0.0001 HCl (4.01) is nearly the same as that of N 0.001 acetic acid. For the purposes of water examination, a rough approximation of the hydrogen-ion concentration suffices, and this can be ascertained by the use of certain dyes as indicators. A set enabling the *pH* from 4 to 13 to be determined answers every purpose.

The determination of the *pH* value enables waters to be divided into distinct classes:—

1. Those which contain no free carbonic acid, but which contain carbonates, with or without bicarbonates. The *pH* of these waters exceeds 8.

2. Those which contain no carbonates, but contain carbonic acid and bicarbonates. This group includes the great majority of waters,

the *pH* value lying between 4.5 and 8. If the *pH* exceeds 4.5, and, after boiling to drive off the free and semi-combined carbonic acid, the value exceeds 7, carbonic acid is the only acid present.

3. Those waters which contain some free acid besides carbonic, and which, therefore, contain neither carbonates nor bicarbonates. In these the *pH* is 4.5 or under, and remains under 7 after boiling.

The first group contains waters of the type yielded by the Thanet Sand where it underlies the Chalk in the London Basin. They are occasionally met with elsewhere, and are probably much more common than is usually surmised.

Members of the third group occur chiefly on the moorlands in the neighbourhood of manufacturing towns. Probably the SO_2 , given off during the combustion of coke, becomes oxidised in the air to SO_3 , and this is brought down with the rain. In lime-burning districts we have found sulphurous acid in the rain collected quite near, and sulphuric acid in that collected two miles away in the direction of the prevailing wind. When such rain falls upon moorlands, the rock may contain enough soluble carbonate to neutralise part or the whole of the acid. In contact with the roots of plants containing salts of organic acids, the sulphuric acid may disappear, liberating an equivalent of the organic acid. For this reason moorland waters containing free mineral acids are very rare.

We have met with several samples of well water containing a free mineral acid, and as these contained an excessive amount of nitrates, the probability is that the free acid was nitric. One came from a well on a sewage farm, and another was in a cottage garden. The cause of the waters containing free nitric acid can only be surmised. Obviously, the soil from which the water was derived must have been practically free from carbonates. In such a soil bacteria may produce nitric acid, which appears in the subsoil water as such, whereas in any subsoil containing carbonates (as is almost invariably the case) the acid would be neutralised.

In processes of softening and purifying water by means of excess lime, *pH* indicators are invaluable, as by this simple determination it is possible to ascertain in a moment whether too little, the correct quantity, or an excess of lime is being used. This process was worked out at the Langford research laboratory, provided for us by the Southend Water Company.

Knowledge of the *pH* is required in the choice of coagulants for water purification. Alumina sulphate, for example, is generally most effective at *pH* 6.7, whereas ferrous sulphate coagulates well at a high *pH*. Ferric sulphate is effective over a wide range. For the removal of manganese by coagulation a high *pH* is essential.

When, for instance, alumina sulphate is used in the treatment of soft moorland waters, it is usually necessary also to add lime or chalk to raise or maintain the *pH* at the optimum value of 6.7. Such waters, after clarification, may still have corrosive properties, and a final adjustment of the *pH* by a further addition of lime is often required.

Measurements of pH are of great value in the control of anti-corrosive treatment and of water-conditioning following lime-soda softening. It should be noted, however, that, in the former process especially, the pH alone is insufficient to indicate whether a water will be corrosive to metals or not, but the pH, considered together with the calcium content, alkalinity and total salinity, shows whether the water is over- or under-saturated with calcium carbonate, and this is the determining factor. Baylis¹ has published a graph which gives the carbonate saturation in terms of pH and total alkalinity, and Langelier² has devised a formula which is based on these, together with the total calcium and total salinity and which enables to be calculated the " pH_s ," or the pH at which any given water is in equilibrium with solid calcium carbonate. The difference between the actual pH and the calculated pH_s gives the "saturation index." A positive index indicates over-saturation with $CaCO_3$ and a tendency to deposit a protective layer in pipes, etc. A negative index indicates under-saturation or a tendency to dissolve existing coating (see also p. 696).

The continuous measurement of pH is so useful in such processes of water treatment that many works are now furnished with "pH recorders" which provide a continuous record of the pH. In some cases, automatic control of the chemical dose is governed by the same means. A description of this type of apparatus is given in Chapter XVI.

¹ *Jour. Amer. Water Works Assoc.*, Vol. 27, p. 220 (1935).

² *Ibid.*, Vol. 28, p. 1500 (1936).

CHAPTER XIII

INTERPRETATION OF THE RESULTS OF CHEMICAL ANALYSIS

If the electric conductivity of the water has been ascertained, an idea will have been obtained of the amount of saline matter held in solution, but practically no hint gained as to its character or the presence of organic matter. Valuable information can be obtained by evaporating a little to dryness and igniting the residue.

Residue left on the Evaporation of a Water. In good waters the residue left on evaporation over the water bath is quite free from colour. In other waters, the opacity of the residue and the effects produced on stronger heating (decrepitation, fusion, discoloration, etc.) all convey information to the intelligent and experienced observer. Charring indicates the presence of organic matter, and, if accompanied by a disagreeable odour, generally indicates that this organic matter is of animal origin. When merely a trace of such matter is present, there may only be an evanescent browning or blackening, usually most evident towards the periphery of the saline residue. When there is an abundance of nitrates present, the organic matter may be decomposed without any obvious charring or discoloration, or the carbon may be observed to scintillate. The presence of iron is usually indicated by the brown tint of the residue, rendered more evident upon ignition.

If the analyst constantly uses the same quantity of water for evaporation, he can at a glance tell if the saline residue is excessive in amount, but if the E.C. has been determined, this fact is already known, and, as before stated, it is often merely necessary to state whether this saline residue is excessive or otherwise, without determining its exact quantity. For this purpose some knowledge of the source of a water is necessary. An upland surface water may leave an exceedingly small residue, 3 to 6 parts per 100,000, whereas water from the Chalk and other formations may give many times this quantity. Some large public supplies deriving water from most diverse geological strata give as much as 150 parts of solid residue per 100,000. As the quality, as well as the quantity, of the saline constituents is of importance, the hardness, chlorides and nitrates should be determined, and, unless these account for nearly the whole of the saline matter, a more complete analysis is desirable. For example, the alkaline waters previously referred to often have a hardness of only a few degrees, contain the merest trace of nitrates, and the chlorides may not account for half the total saline matter. Further analysis shows that the waters contain

large quantities of sodium carbonate and sulphate, neither of which is estimated in the ordinary course.

A properly-made quantitative estimation of the total solids affords a valuable check on the results of the more detailed analysis, whilst a qualitative or rough quantitative estimation often affords interesting information with regard to the quality of the water.

The saline constituents found in waters from various sources are given in the tables of analyses contained in Chapter XXV. In an ordinary sanitary analysis, only the chlorides and nitrates are usually estimated, but the estimation of the total, permanent, and temporary hardness gives some indication of the amount of the calcium and magnesium compounds present, and the proportion existing as carbonates. The above estimations frequently furnish all the information which is required with reference to the nature of the saline constituents of a water.

Hardness. For ordinary sanitary purposes it is not always necessary to estimate the amount of calcium and magnesium compounds present. It suffices usually if the soap-destroying power of these salts is determined. The soap-destroying or curdling power is of importance, as it affects the utility of the water for most domestic purposes. If excessive, it curdles soap to such an extent as to cause great waste, and it may render the water practically useless for washing purposes. Other objections will be mentioned later. For household purposes generally, a water with but little soap-destroying power is desirable, but there is no proof that such a water is better for the health of the persons using it. This has already been considered in the section "What constitutes a Pure and Wholesome Water?"

Nearly all waters possess both temporary and permanent hardness, a portion only of the calcium and magnesium salts being removable by boiling. Generally speaking, the less the permanent hardness the better is the water adapted for domestic and manufacturing purposes, and a water in which the permanent hardness is due to magnesium salts is not considered so satisfactory as one in which the hardness is due to calcium salts.

Occasionally a water may contain sufficient iron or zinc salts to affect appreciably the hardness, but the presence of considerable quantities of sodium and potassium salts appears to have only a very slight effect upon the soap-destroying power. The so-called hardness represents the soap-destroying power, and nothing more, and the attempts which have been made to deduce from the hardness information with reference to the actual quantities of calcium and magnesium salts present have introduced many fallacies and caused great confusion. There are few waters which do not contain salts of magnesium, and the soap-destroying power of these salts is much greater, weight for weight, than that of the salts of calcium, and the character of the salts and their properties have a marked effect upon the analytical results. However the soap test is applied, usually only approximate results can be obtained, since the end reaction is not always well defined,

becoming more and more indefinite as the proportion of magnesium salts increases. We have ceased to attempt to determine the hardness to less than half a degree, since different chemists obtain results from the same water differing by two or three degrees. This has occurred in the same laboratory, using the same solutions and the same water. Any attempt, therefore, to express the degrees of hardness to the first decimal place is futile. If it is desired to obtain information with reference to the amount and character of the calcium and magnesium salts present in a water, a proper quantitative analysis should be made instead of running the risk of drawing erroneous conclusions from the results of the soap test.

The hardness or soap-destroying power of a water is, in this country, often expressed in degrees (Clark or English), *i.e.*, as calcium carbonate, grains per gallon or parts per 70,000. The standard of 1 part in 100,000 parts of water, generally adopted in France, and now largely adopted in this country, is the one used in this work. To convert it into the grains per gallon standard, multiply by 0.7. As stated in Chapter III., and repeated here for convenience, a water of hardness (expressed in parts per 100,000) less than 5 may be considered a soft water; over 5 and under 10, a moderately soft water; over 10 and under 15, as slightly hard; over 15 and under 20, as a moderately hard water; over 20 and under 30, a hard water; over 30, a very hard water.

When a hardness of 30 is approached, the water becomes very objectionable for washing purposes, but towns in this country have public supplies of greater hardness, and there is no doubt that they are perfectly wholesome. In fact, we find well-known health resorts with water supplies of a hardness exceeding 40 parts per 100,000 (*i.e.*, over 28 on Clark's scale).

In connection with a Bill before Parliament, when the hardness of the proposed supply was in question, the hardness of the larger public supplies in this country was tabulated as under :—

Public supplies with a hardness of under 5	140 or 37 per cent. . .
Public supplies with a hardness of 5 but under 10	69 „ 18 „
Public supplies with a hardness of 10 but under 15	50 „ 13 „
Public supplies with a hardness of 15 but under 20	62 „ 16 „
Public supplies with a hardness of 20 and over	62 „ 16 „

The hardness of some of the waters used is extraordinary. The L.G.B. Report on the water supplies, England and Wales (1914), gives the hardness of practically every supply, and it must be remembered that the hardness is given on Clark's scale. Seven authorities admit supplying a water with a hardness of 30 degrees (Clark), but two of them only are towns of any importance.

According to the same Report, the hardness of the M.W.B. supplies is as under :—

	Degrees, Clark.
Thames derived water.	15.6
Lee derived water	17.3
New River derived water	16.6
Kent wells	21.8

In the report of the Director of Water Examinations, Metropolitan Water Board, for the year ending December 31st, 1937, the average figures for hardness, expressed in parts per 100,000, are :—

Thames raw water	21.9
Lee raw water	27.8
New River raw water	26.2
Kent wells	27.0
New River, filtered	24.7
River Lee, filtered	25.6
River Thames, filtered	21.6

We are aware of a few public water supplies in England having hardness of 45–55 parts per 100,000. These have been in continuous use for many years, and, so far as we are aware, there is no evidence of any injurious effect on health.

Although water of such hardness may not be unwholesome, it is justifiable, in our opinion, to regard it as unfit for general domestic purposes. If the hardness is chiefly “permanent,” and especially if due to magnesium salts, the unfitness would be emphasised, but even then it could not be definitely certified as “unwholesome.”

If any appreciable portion of the hardness is possibly due to free carbonic or other acid, or to salts of zinc or iron, the amount of these should be determined. It is rare indeed that this is necessary.

TABLE I
SHOWING 529 WATER SUPPLIES IN GREAT BRITAIN AND IRELAND GROUPED
ACCORDING TO HARDNESS (ABSTRACTED FROM “BRITISH WATERWORKS
DIRECTORY,” 1936)

Total hardness in parts per 100,000.	Number of supplies.	Percentage.
0–5 . . .	115	22
5–10 . . .	102	19
10–15 . . .	58	11
15–20 . . .	60	11
20–30 . . .	127	24
30 and over .	67	13
Total .	529	100

An exceedingly soft water should always be examined to ascertain whether it has any action on lead, zinc, and iron, and any water with a temporary hardness below 4 should be similarly examined, as such waters usually act on these metals.

The L.G.B. Report previously referred to is now unreliable, since in some cases water-softening plants have been installed, and in others, new sources of supply have been obtained.

The preceding table, compiled from the "British Waterworks Directory" (1936), shows the general position with regard to the hardness of the public water supplies of Great Britain.

The greater proportion of the soft water supplies are found in Scotland and Wales, and the following table shows the hardness of 232 public water supplies in England which we have recently examined.

TABLE II
SHOWING 232 WATER SUPPLIES IN ENGLAND, GROUPED ACCORDING TO
HARDNESS

Total hardness in parts per 100,000.	Number of supplies.	Percentage.
0-5 . .	39	17
5-10 . .	22	9.5
10-15 . .	27	11.5
15-20 . .	29	12.5
20-30 . .	79	34
Over 30 .	36	15.5

Chlorides. In most waters the whole of the chlorine present is in combination with sodium as sodium chloride, but occasionally calcium and magnesium chlorides are also present. Potassium chloride in appreciable amount is usually found only in waters containing such other constituents as would place them in the category of mineral waters. The amount of sodium chloride present will closely approximate to the amount of chlorine multiplied by 1.65 (or divided by 0.6), but it is usual to express the chlorides in terms of chlorine. Thus a water containing 6 parts of chlorine per 100,000 will contain approximately 10 parts of sodium chloride if the whole is combined with sodium, and very little less than 10 parts of mixed chlorides if a small portion is combined with calcium or magnesium. The error only becomes marked if there is much magnesium chloride present, and this is very rarely the case unless sea water is gaining access to the supply examined. This is obvious from the fact that 35.5 parts of chlorine represent 58.5 of sodium chloride, 55.5 of calcium chloride, and 47.5 only of magnesium chloride, these salts containing 60, 64, and 74.6 per cent. of chlorine respectively.

Practically all soils and rocks contain chlorides in quantities varying from the merest trace to the rock salt formation which consists of almost pure sodium chloride. Hence all waters, including even the purest rain water, which derives from the air a trace of spray from the ocean, contain chlorides. Chlorides may, in the neighbourhood of the sea or tidal rivers, be derived from sea water which has entered the water-bearing stratum. Sewage and urinary matter from stables and byres contain chlorides. Occasionally, also, land is salted for certain agricultural purposes, and this has been known to affect appreciably the amount of chlorides in the subsoil water. Some years ago a sample of water from a shallow well, sunk to supply a mansion, was found to contain so much salt that the site was examined. The well, which was only about 8 feet deep, had been sunk in a field far from any possible source of pollution. There was nothing to explain the presence of all this salt, and another well, sunk in a different part of the field, yielded a water containing a far smaller quantity, yet much greater than the other shallow wells on this patch of gravel. The only possible explanation was the "salting" of the field. This experience is not uncommon, but, as a rule, the amount of chlorides from a given stratum, and in a particular locality, varies only within narrow limits. In many districts, however, the variation is sufficient to render it impossible to say that any slight difference observed is due to sewage contamination.

Urine contains nearly 1 per cent. of sodium chloride, and the whole of the sewage of 1,000 people deposited on a square mile of porous gravel would not increase the amount of sodium chloride in the gravel water by, on an average, more than 0.5 part per 100,000. In Massachusetts, an attempt has been made to map out the country into areas of equal chlorine contents in the unpolluted waters. The points of equal amounts, when connected, are termed *isochlors*. The waters near the coast contain about 0.6 part per 100,000 of chlorine, and proceeding westward from the coast, this gradually falls to about one-eighth of the amount. Such small quantities of chlorides are rarely found in this country, and all attempts to map out isochlors for England have proved futile.

Over limited areas, where the water-bearing stratum is uniform in character and continuous, the amount of chlorides found in localities far removed from the possibility of pollution may be considered as the "normal," and any excess found elsewhere in water from the same stratum may be attributed to present or past pollution. In this country at least, it is practically impossible to obtain from deep or shallow wells water which has not, in its previous history, been in contact with manured soil. The surface soil possesses such oxidising and purifying qualities, due chiefly to the nitrifying organisms therein, and the subsoil usually filters so effectively, that practically the whole of the organic matter and the bacteria derived from the sewage disappear before the water has travelled any considerable distance. As the presence of ashes indicates that there has been a fire, and, therefore, that organic matter has been consumed, so the presence of an excess

of chlorides in water and, as we shall see later, of nitrates also, indicates that the water has contained organic matter, presumably of animal origin, but that it has been oxidised or burnt. Unless a large amount of this organic matter remains unoxidised, or the bacteria which accompany it are not removed by the natural process of filtration, the water may be perfectly wholesome. The chlorides and nitrates are the ashes of the organic matter of sewage, as carbonates, silicates, etc., are the ashes of wood.

Several times we have had occasion to examine the water from every well in a parish, and have always found great variations in the amount of chlorides, the amount increasing towards the centre of population, and in the direction of the flow of the subsoil waters. Taking 4 parts of chlorine per 100,000 as the normal, the amount often increases to 20 or upwards. In all cases this increase in chlorine is accompanied by an increase in nitrates, and in most cases by an increase in the amount of ammoniacal nitrogen and organic matter. Obviously, with such an amount of chlorides, derivable from no other source than sewage as far as could be ascertained, the ground water must have consisted almost entirely of sewage more or less purified. Such a polluted subsoil is entirely unfit to serve as a public source of water supply. As a rule, sewage contains about 5 parts of chlorine per 100,000 above that found in the water supply, allowing 80 gallons of water per head of population per day; hence in cases such as the above, where the chlorine rises to 20 parts, the amount of water used daily must have been very small, or the same water must have been used over and over again, each time becoming more highly charged with sewage or the products of its oxidation. The amount of chlorides found in potable waters varies so much that safe conclusions as to their source cannot be drawn without confirmatory evidence. If the chlorides are derived from sewage, this can usually be shown by determining the amount of nitrates in the water, since both will rise and fall together. Hence, when a water contains a large amount of chlorides and a correspondingly large amount of nitrates, the origin of both may be said to be certain. Occasionally further proof can be obtained, as in the remarkable instance briefly referred to on p. 53. Here the well yielded an unfailing supply of water, which was used for all domestic purposes, and upon analysis it was found to be remarkably free from organic matter. It was said to be always cool, bright, and sparkling, probably due to its containing a very excessive amount of chlorides and nitrates derived from the sewage percolating into the subsoil, and we expressed the opinion that the water was a concentrated purified sewage. This was not believed at the time, but when the cesspool was filled in and the sewage carried elsewhere, the well ran dry. There is no doubt that in this case the same water was used over and over again. After being defiled by the closet, slops, etc., it ran into the cesspool, then filtered through the soil, during which the organic matters became completely oxidised, and ultimately the water found its way back to the well, to be utilised again for domestic purposes. Doubtless at times, possibly

after heavy rains, the cesspool contents filtered too rapidly for complete purification to be effected, and this impure water may have been the cause of the ill-health amongst the consumers.

The same kind of thing occurs in numerous villages where the contents of cesspools are allowed to percolate into the subsoil water from which the domestic supply is obtained by means of shallow wells. Were it not for the remarkable purifying action of the soil, epidemics of typhoid fever would be far more frequent. As it is, communities continue to use such waters, and often, on account of their cool and pleasant taste, and bright, sparkling appearance, consumers prefer them, even after a public supply of pure water has been laid on.

Near the sea the influx of sea water will be indicated by an increase in the chlorides, but to prove this it is necessary to estimate the magnesium in various samples in order to ascertain if this increases *pari passu* with the chlorine. The hardness will increase also, the temporary hardness very slightly and the permanent hardness more markedly. Analyses (*vide* tables, Chapter XXV.) of Gosport waters may be referred to as examples of waters affected by impregnation of the subsoil with tidal water. The chlorine in sea water is about 1,835 parts in 100,000; hence the infiltration of 1 per cent. will increase the chlorine in a water by 18.85 parts per 100,000. The chlorides in tidal rivers vary very considerably, decreasing as the river is ascended. Between Woolwich and Leigh, on the Thames, we have found it to vary from 900 to 1,800 parts per 100,000, but higher up the river it becomes very much less. The detection of the presence of tidal water is of especial importance if such water is known to be sewage-polluted, but here, again, percolation through the soil or rock may have removed practically every trace of organic matter. Analyses of waters from Grays (*vide* tables), affected by the influx of very impure Thames water below the outfalls of the London sewage works, have only very seldom yielded results indicative of sewage contamination, although we have made chemical and bacteriological analyses of numerous samples.

Occasionally the decrease in the amount of chlorides in a well water has some significance. In more than one instance the infiltration of subsoil water into a deep well has been detected by a decrease in the chlorides. Many Essex deep wells contain a considerable amount of sodium chloride, and in the same well this varies very slightly from year to year. If subsoil water gains access to such wells the chlorides are proportionately decreased. The presence of so much sodium chloride in these well waters has in more than one instance led the analyst astray. In one case the chemist gave at length his reasons for believing that the excessive amount was due to sewage pollution. As a matter of fact, the well from which the water was derived was about 1,000 feet deep, bored in the open country far from any habitation and where sewage pollution was highly improbable. It was one of the purest of natural waters, free from the slightest indication of contamination by either sewage or manure.

Some public supplies contain from 50 to 70 parts of sodium chloride per 100,000, and a few up to 100 parts per 100,000, but they appear to be unobjectionable, unless fluoride is also present. A very much smaller quantity of calcium or magnesium chloride would render a water absolutely useless for many domestic purposes on account of its soap-destroying power and disagreeable taste; even 4 or 5 parts per 100,000 of these salts are objectionable. These chlorides have a corroding effect on steam boilers; hence where the water is to be used for boilers and other manufacturing purposes, as well as for a domestic supply, their presence is extremely undesirable.

Paper works, galvanising works, and other manufactories and base-exchange water-softening plants often discharge large quantities of effluents containing chlorides, and the possibility of any excess found in a river or stream being due to such a cause must not be forgotten.

Phosphates. The phosphorus of all living tissue, vegetable and animal, in process of disruption is finally oxidised to phosphates. Phosphates are found, sometimes in appreciable proportion, in certain rocks and sands, such as the Greensand, and are extensively used in chemical or artificial manures.

An adequate supply of phosphorus is necessary for life, and is obtained from a properly balanced dietary of ordinary foodstuffs. It is excreted in the urine in the form of phosphates, and in man the average daily phosphate content of urine is approximately 2.5 grams expressed as P_2O_5 . Phosphates are, therefore, found in sewage, manure, and soil, and consequently in water. Their presence in water may be indicative of the original presence of organic matter, but when found they merely confirm the more definite indications given by nitrates and chlorides which are quantitatively greater and no more difficult to determine. The nitrates and chlorides having been estimated, no further information in respect of pollution is to be obtained from the phosphate figure, and for this reason it can be omitted from routine water analyses without loss.

Phosphates are used in the treatment of water under various trade names, such as "Clensol," and "Calgon," and their detection and estimation may sometimes be required in this connection.

Also, phosphates have considerable significance in relation to water biology, although they may be present only in infinitesimal traces. It has been demonstrated that phosphates, together with silica, are intimately related to the presence and development of phytoplankton, *i.e.*, the class of microscopical organisms which require light, such as the Diatomaceæ and Chlorophyceæ. The phosphorus and silica contained in the fabric of the organisms themselves have been determined for certain marine algæ, and it has been shown that the depletion of phosphorus and silica in the sea water was equivalent to the amount of these elements in the growths.¹

¹ W. R. G. Atkins, Sc.D., F.R.S., *Journal of the Marine Biological Association of the United Kingdom*, vol. xiii., No. 1, December, 1923, p. 119, and vol. xv., No. 1, February, 1928, p. 191.

Investigations on these lines with regard to fresh water are in progress, and it has been shown in the case of the supplies of the Metropolitan Water Board that the phosphate content of the raw, stored, and filtered waters are highest in the winter months of November to February when algal life is dormant, and lowest during the months of warmer weather when algal activity takes place.

The following are examples of the phosphate figures obtained during the year 1937¹ :—

PHOSPHATES, AS PO_4 , IN PARTS PER 100,000

	Highest.	Lowest.
<i>Raw Waters</i>		
River Thames	0.046 in January	0.014 in September
River Lee	0.06 in January	0.017 in June
New River	0.06 in January	0.013 in June
<i>Stored Waters</i>		
Stoke Newington Reservoir .	0.059 in January	0.003 in June
Walthamstow Reservoir . .	0.026 in January	0.010 in May
Queen Mary Reservoir . . .	0.024 in December	0.004 in May
<i>Filtered Waters</i>		
Thames derived	0.022 in January	0.011 in May
Lee derived	0.026 in January	0.010 in May
New River derived	0.054 in January	0.010 in June

Generally the highest phosphate contents of the waters are obtained in the four months of November, December, January and February.

Comprehensive figures on these lines have not yet been accumulated, but in due course, when such have been obtained and the phosphorus and silica metabolism of algæ is better understood, sufficient information may be available to enable not only control, but also prevention, of troublesome outbursts of algal growths in stored waters.

Phosphates are found in underground waters in minute traces, and the amounts vary according to the original pollution of the waters and strata through which it has percolated. In a general way there is often correlation between the nitrates and the phosphates, and this is illustrated by the following figures extracted from the 32nd Annual Report of the Metropolitan Water Board, 1937 :—

Deep Well Waters

RESULTS EXPRESSED IN PARTS PER 100,000—AVERAGES

	Oxidised Nitrogen.			Phosphate as PO_4 .		
	Highest.	Lowest.	Average.	Highest.	Lowest.	Average.
<i>Kent District</i>						
21 sources	1.14	0.31	0.55	0.022	0.007	0.011
<i>Northern District</i>						
14 sources	0.26	0.01	0.04	0.007	0.001	0.003

¹ 31st Annual Report, Metropolitan Water Board, London, 1936, and 32nd Annual Report, Metropolitan Water Board, London, 1937.

Nitrates. The amount of nitric acid combined with bases present in potable waters is expressed in several different ways, but the majority of chemists now express it as nitric nitrogen or nitrogen in nitrates. Throughout this work the term "nitric nitrogen" will be used to represent the amount of nitrogen present in the nitrates found in water.

It is probable that the nitrates found in water are mostly derived from nitrogenous organic matter of animal origin. Vegetable matter, by oxidation in the soil, yields very little nitric acid, whilst animal matter yields a large amount. The nitrogenous bodies of animal origin readily decompose and a part of the nitrogen ultimately becomes converted into nitric acid, which, reacting upon the carbonates in the soil, forms some of the nitrates which are found in subsoil and deep well waters. There are many stages in the decomposition of nitrogenous organic matter, which is brought about by the activities of soil micro-organisms.

All fertile soils abound in microscopical life of great variety, including bacteria, moulds, algæ and protozoa, an important function of this life being the decomposition of vegetable and animal organic matter.

The soil bacteria include many species having different activities. They are mostly dependent one upon the other, and the nitrogen and other cycles necessary for the continuation of life are completed by their joint efforts.

The majority of these bacteria obtain their energy from both inorganic and organic compounds, but some can do so solely from inorganic matter.

An important part of the nitrogen cycle is that taking place in the soil where, as a result of the divers and associated activities of micro-organisms, nitrogenous substances in various states are either broken down or built up.

The proteins of waste organic matter in the soil are broken down by bacteria to amino-acids and then to ammonia, of which some is utilised directly by vegetation and elaborated to protein, whilst some may be retained by the mineral constituents of the soil. The ammonia thus formed may also be either converted into proteins, or oxidised first to nitrites and then to nitrates, in each case by various groups of organisms. The nitrates produced in the soil provide the source of nitrogen to various low forms of life, and also to vegetation, when protein is again synthesised, and thus the cycle continues.

On the other hand, the nitrates may be broken down by another group of micro-organisms which possess reducing or denitrifying abilities, being converted first to nitrites, then to oxides of nitrogen, and finally to free nitrogen. There are also soil bacteria which, under certain conditions of association with roots, are able to fix free atmospheric nitrogen and render it available for plant life, but the greater part of the nitrogen required by vegetation is obtained in the above manner. The nitrogen cycle is a continuous and highly complex process in which many soil organisms take part. In the reduction of nitrates, for example, some bacteria can produce both nitrites and

ammonia, others nitrites only, and still others are able to reduce nitrites to ammonia but not nitrates to nitrites.

It is evident that the ammonia, nitrite and nitrate content of a water must be influenced by the organic matter present in the soil with which it has been in contact and the activities of the life contained therein. Many of the soil micro-organisms concerned in the nitrogen cycle must also be present in the waters of rivers, lakes, impounding reservoirs, etc., and thus be responsible for changes in the relative proportions of nitrogen in ammonia, nitrites and nitrates. These changes are readily observed by systematic analyses, and in the process of sand filtration, for example, there is normally a loss of ammonia in the water as a result of the biological activities described above as taking place in the soil.

The Rivers Pollution Commissioners found that 97 per cent. of the combined nitrogen in London sewage was converted into nitrates by slow percolation through 5 feet of gravelly soil. As average London sewage contains 10 parts of combined nitrogen in 100,000 parts, the latter amount of sewage would yield 9·7 parts of nitric nitrogen. A water containing 10 per cent. of such purified sewage would yield about 1 part of nitric nitrogen per 100,000. The purest rain water contains a trace of nitrates, on an average equivalent to 0·03 part of nitric nitrogen per 100,000. This is probably due to the oxidation of atmospheric nitrogen during electric discharges. Vegetable matter in its comparatively slow decay produces very little nitric acid; hence, as no other source of nitrates is widely distributed, most of the nitrates found in water must have been derived from animal matter, and, therefore, in the great majority of cases, from manure and sewage. At one time the large amount of nitrates found in a certain water supply in Yorkshire was a mystery, but it was ultimately found that the well was sunk near some trenches which had been filled with bodies after one of the battles during the Civil War. Bones in quantity were found on sinking a pit, and when pumping was going on at the works the water level in the pit gradually fell, to rise again when the pumping ceased. In another instance, when a well was being sunk, a curious stratum containing much organic matter was reached, the water from which was loaded with nitrates. The opinion of the geological expert was that the bed was an old guano deposit.

The nitric nitrogen occurring in waters used for domestic purposes varies from 0·00 to 7 or more parts per 100,000, though few waters are found with either of these extremes. Deep wells are known to yield waters which are frequently free from nitrates, and the samples of water which we have examined containing such large amounts as 7 parts of nitric nitrogen per 100,000 have been from shallow wells. In one such case we found no less than 15 parts per 100,000 of nitric nitrogen, but this is very exceptional. On account of this great variation, it might be suggested that the presence of nitrates could be ignored, but in our opinion it is unwise to express an opinion upon a water without knowing approximately the amount of nitrates present, and something

about their most probable source. Waters from many gravel beds contain 2 or more parts of nitric nitrogen per 100,000, doubtless derived from manurial matter, yet such are used for public supplies and are perfectly wholesome. There is also a seasonal variation in waters from the same spring or well, but not nearly so marked as the variation in different gravels. No standard can possibly be adopted for the amount of nitrates permissible in a potable water. The nitrates are as harmless as the chlorides, and, though excess of both indicates previous sewage or manurial pollution, if the sources from which they are derived are sufficiently remote, and the water is free from objectionable bacteria, their presence may be ignored. Chemical analyses cannot be depended upon to indicate the proximity or otherwise of the source of pollution, and epidemics of typhoid fever have occurred amongst populations using water containing very small amounts of nitrates. On the other hand, many large villages using water containing from 1.5 to 5 parts of nitric nitrogen per 100,000, for the last thirty years at least, have to our knowledge remained free from typhoid fever, save when an occasional case has been introduced from without.

Notwithstanding this, a water cannot be recommended for domestic use which has a much greater content of nitrates than appears to be the normal in the best waters from that particular water-bearing stratum. Any excess necessitates a careful investigation of the source of the water.

When animal matter undergoes decomposition in the absence of air, and in the presence of water containing nitrates, these latter are deoxidised and disappear; consequently nitrates are rarely, if ever, found in putrid sewage. Ferruginous sand may also reduce nitrates to ammonia, and all growing crops absorb nitrates from the soil. Hence the amount of nitrates in a water may not represent the whole of the previous pollution to which the water has been subjected.

Where nitrates are in process of formation or of reduction, traces of nitrites are generally found; hence some analysts lay great stress on the test for the presence of nitrites. In the analysis of samples collected from steel-lined boreholes or distribution systems, particularly where galvanised-iron is included, it must not be overlooked that nitrates in the water may be reduced to nitrites and ammonia. It is generally advisable to submit a water containing an excess of nitrates to a bacteriological examination, the sample being taken a day or two after a heavy rainfall, in order to ascertain whether both soil purification and filtration are efficient. A water which contains any excess of nitrates, and which is liable to become turbid or opalescent after heavy rainfalls, should be unhesitatingly regarded as unsafe for domestic purposes.

Nitrites. Nitrites are nearly always found in sewage effluents from the so-called bacteria beds. Their presence indicates that the organic matter in the sewage is undergoing active oxidation or nitrification, and that the process is not complete. Hence, a water containing a trace, however slight, must be regarded with suspicion, unless some other source is found from which it has more probably been derived.

In partially purified sewage containing nitrites, an excessive amount of free ammonia is also found, but unfortunately other sources of nitrites besides sewage also produce ammonia, so that this fact does not throw any light on the origin of the nitrites. As previously stated, many waters containing nitrates, if allowed to stand in contact with iron, zinc, or lead in pipes or cisterns, act upon the metal, the nitrates being in part reduced to nitrites and ammonia. Ferruginous sand may also effect this reduction. In such cases careful tests will detect some trace of the metal in solution. Unless, therefore, indications are obtained of the presence of an inorganic reducing substance, or some other explanation is acceptable, the nitrites must be attributed to the imperfect oxidation of animal matter, and the water be regarded as unwholesome or dangerous.

The possibility of nitrites being derived from any other source than sewage or manure is too often ignored, and has led to many waters of perfectly satisfactory quality being reported as sewage-polluted. That this reduction of nitrates by metals is a comparatively frequent source of nitrites, we have proved by numerous experiments made for the purpose; and, when applying tests to ascertain the action on metals of water containing nitrates, we have practically always found that the oxidation of the metal was accompanied by the reduction of the nitrates to nitrites and ammonia. Also, nitrites frequently occur in purified river waters as a late effect of sterilisation by the chloramine process.

Besides the micro-organisms found in sewage and manure which are capable of reducing nitrates, there are other reducing organisms which are not derived from such objectionable sources. Thus, occasionally, a water is found containing traces of nitrites which, from the examination of the source, could not be derived from sewage or manure, and which did not appear to be due to any reducing action from contact with metals. A water of this kind should be passed as safe only after a most careful examination of the source of supply has proved sewage and manure contamination to be impossible. Nitrites in waters from newly-constructed wells (*vide* section on this subject) are apparently due to some reducing agent in the brickwork, since after a time the water yielded by these wells often becomes free therefrom.

The amount of nitrite in a water is rarely determined, as such a determination serves no useful purpose since it varies from day to day, and almost from hour to hour.

There is reason to believe that nitrites are sometimes said to be present in a water when the reaction giving this indication is really due to the presence of traces of the higher oxides of manganese. In one case the water supplied by a large public company was adversely reported upon owing to the alleged presence of nitrites. The Company's analyst found no nitrites in the water. The springs and reservoirs were examined and a large number of samples taken. Employing one test, the nitrite reaction was obtained with all, but it was particularly marked in a sample taken from a small pool adjoining one of the

reservoirs and covered with an active confervoid growth. When these waters were filtered, only the pool water gave the reaction, and when confirmatory tests were applied it was found that the pool water alone contained nitrites. Evidently they were being formed by the reducing action of the confervoid growth on the nitrates present. A further investigation showed that the reaction first obtained (with acid and potassium iodide) was due to a trace of manganese, and that so little as 1 part of manganese dioxide in 40 million parts of water suffices to give the iodine reaction in a few minutes. This amount represents approximately 1.5 part per 100 million of water. Upon testing the water residues, all were found to contain more than this quantity.

A little of the confervoid growth was added to some of the company's water and exposed to bright sunlight, but no nitrites were formed. A little of Warrington's solution (solution of ammonium phosphate, etc.) was then added and the water again exposed to the sunlight. In a few hours nitrites were easily detected. There can be no doubt, therefore, that nitrites may occur in stored waters which are not sewage polluted.

It should be remembered also that nitrites are given off in smoke from burning fuel, and that traces are found in the products of the combustion of gas and in tobacco smoke. Distilled water in laboratories often contains minute traces of nitrites due to these causes, and traces found in reservoir water have been attributed to the smoke from the pumping station; but we have been unable to confirm this.

Free Ammonia. Very few natural waters are found which do not contain some trace of ammonium salts. Except in acid rain and moorland water, it probably always exists as ammonium carbonate. By the distillation of such waters, with or without the addition of a little alkali, the ammonia is carried over in the distillate, and is spoken of as "free" ammonia, to distinguish it from a further quantity of ammonia which can be obtained by adding a strong alkaline solution of potassium permanganate to the concentrated water and continuing the distillation. This latter quantity is spoken of as the "albuminoid" ammonia, a term which is misleading, since this ammonia does not exist in the water, but is produced by the decomposition of the nitrogenous organic matter by the alkaline permanganate.

To understand the significance of the free ammonia and of the quantity present, it is necessary to consider the various sources from which it may be derived. Rain and snow always contain a trace, the first fall containing most. The amount varies very considerably, from 0.01 to 0.2 part per 100,000, but is usually about 0.06.

All fertile soils and all decaying vegetable and animal matter contain ammonia, yet rain falling upon manured ground may reach the subsoil water practically free from ammonia, the nitrifying organisms having converted it into nitrates. Urine of men and animals yields large quantities of ammonium carbonate, hence sewage is rich in ammonia. Nitrates by their reduction yield ammonia; consequently a water containing nitrates which has been subject to the reducing

action of ferruginous sands, or of considerable lengths of metal pipes, may contain ammonia.

Certain low forms of vegetable life in water, *e.g.*, *Crenothrix*, produce ammonia, but whether they produce it during life or only by their death and decay is not yet determined.

Dr. Munro,¹ in his studies on nitrification, observed that a large quantity of ammonia "may disappear in a few days with a corresponding increase of nitrate; this is specially liable to occur in summer, and should a week elapse between the analyses of the same sample of water some very striking differences in the results would be manifest, although each analysis might be perfectly correct." With reference to the presence in water of ammonia derived from other sources than manure or sewage, he stated: "Ammonia may be present in the stagnant waters supporting confervoid growths, as a by-product of the reduction of nitrate by various organisms." He adds, however, "Ammonia formed by reduction is not of frequent occurrence in well waters, unless it is accompanied by ammonia resulting from putrefaction."

It is obvious, therefore, that the ammonia found in water may be derived from harmless sources, or from sources indicating serious pollution. Without knowing from what it is derived, it is impossible to say whether it indicates serious contamination or not. The waters yielding most free ammonia come from the Thanet sands and Chalk in certain parts of the London Basin, waters which generally are free from more than a minute trace of organic matter, and from the slightest suspicion of sewage pollution. (*Vide* Analyses, Chapter XXV.) It is not uncommon, however, for these waters to be erroneously reported as polluted by sewage or urine on account of their high contents of free ammonia.

The amount of ammonia found in the water from a deep well may vary considerably from time to time, and this is due, in many instances, to the reduction of the nitrates existing in the water by the metal of the bore pipes. It is often found that the water first pumped from the boreholes after rest contains a large amount of ammonia which gradually lessens as pumping is continued.

A nitrated water filtered through a layer of sand from the Lower London Tertiary Beds becomes highly charged with ammonia, and apparently the reduction is due to the ferrous aluminate present in these sands. Every sample of such sand examined possessed the power of reducing nitrates.²

It is practically impossible to judge the character of a water from the amount of ammonia present, but wherever this exceeds 0.006 part per 100,000 an endeavour should be made to ascertain its origin. Considered together with the amount yielded by the organic matter present (the albuminoid ammonia), correct inferences can usually be

¹ *Journal of the Chemical Society*, August, 1886.

² "The Alkaline Waters of the London Basin."—Thresh. "Geological Memoirs," Essex.

drawn. Rain waters collected from roofs may contain not only ammonia derived from the air, but a further quantity derived from bird droppings, soot, and decaying vegetable matter which collects on housetops, in gutters, etc. An amount in excess of 0.01 part per 100,000 occurring in a water containing an excess of organic matter almost certainly indicates manurial pollution, but upland surface waters being directly derived from the rainfall may contain 0.01 part without being polluted, and moorland surface water, especially if peaty, may contain the same amount associated with more organic matter and yet be wholesome. Subsoil and spring waters should contain very little ammonia if soil purification has been efficient. It is rare that a really satisfactory water contains more than 0.006 part per 100,000. Deep well waters can only be judged from a knowledge of the amounts usually found in waters from the particular strata from which they are derived, and as such waters should contain an exceedingly minute trace of organic matter, if an excess of both ammonia and organic matter is found, pollution should be suspected. The Essex and London deep wells, previously referred to, which yield waters containing very variable and often very excessive amounts of ammonia when uncontaminated, contain very little or no organic matter. Pure river waters rarely contain more than 0.004 part per 100,000, and any excess is probably due to sewage or drainage from manured land.

From the above observations it will be gathered that no correct inference can be drawn from the results of an estimation of the ammonia only. A water containing much ammonia may be free from manurial or sewage matter, whilst a water containing only a very small quantity may be polluted. Considered together with the amount of ammonia yielded by the organic matter present in the water on distillation with a strongly alkaline solution of potassium permanganate, valuable information is obtainable, often enabling one to suspect sewage pollution.

Even the very small quantity which is sometimes regarded as permissible may be derived directly from sewage; hence the great importance of possessing an intimate knowledge of the source before attempting to interpret the significance of the amount of ammonia obtained from a sample of water.

Ammonia itself is harmless; hence its presence in water has no effect upon wholesomeness, whatever its source, and if it is derived from manurial matter, provided it is not associated with bacteria indicating that the water is from a dangerous source, the quality of the water is not necessarily affected. In the chloramine process of sterilisation, ammonia is added to water in amounts varying from 0.005 to 0.05 parts per 100,000.

Organic Matter. The organic matter content of water is either animal or vegetable in origin. Practically the whole of it must be derived from the lichens and low forms of vegetable life on rocks, mosses and peat on moorlands, the humus of fertile soil, excrement of animals, manurial matters, and possibly sewage. Decaying vegetation in streams, lakes, ponds and reservoirs may contribute to the organic

matter. Whatever its source, there is a natural tendency for it to disappear, the carbon being converted into carbonic acid, and the nitrogen into nitric acid, but in nearly every case a residuum remains which is apparently not easily fermentable or putrescible. "The soil," to quote Dr. Munro, "is the abode of many ferments, some of them having opposed functions, but all lying in wait for suitable conditions which shall encourage one species for a little while until it has done its work and has brought about an alteration favourable in turn to the encouragement of another species. From the soil, these ferments pass into the waters, from which they are not completely removed even by filtration, and the nitric ferment, certainly one of the most subtle of them all, seems little affected by this process. The addition of any ordinary organic matter instantly excites activity in one or other of these ferments, and the effect is soon visible to the eye by the impaired clearness of the water, and to chemical tests by the effect produced on the nitrate of the water."

"The organic matter of potable waters can only be such organic matter as is unfermentable, or, at any rate, not rapidly or easily fermentable. . . . What two compounds, for example, could exhibit a greater contrast than gelatine and potassium thiocyanate? Yet the one is as readily broken down by soil ferments as the other." The soil "ferments" mentioned by Dr. Munro are now referred to as soil micro-organisms, and these were discussed in the section dealing with nitrates.

As all waters at some time in their history must have been in contact with organic matter, and as this organic matter speedily undergoes change, leaving a certain residuum not easily oxidised, it is obvious that an estimate of its amount may often afford very little information of any value. If pollution has been recent, some of the more readily oxidisable matter may remain in the water and be detectable, but even then we may not be able to decide whether this is of vegetable or animal origin.

By no known process can the amount of organic matter in solution in potable water be estimated with any approach to accuracy. The difficulty of the problem is obvious when we reflect that very few such waters contain as much as half a grain of organic matter in a gallon. It is very doubtful whether this organic matter is ever of such a quality as to have any effect upon health, even if it is derived from sewage or manure. Hence an accurate determination of the quantity present would serve no practical purpose, as it is not so much the quantity as the quality which is of importance from the diagnostic point of view. As the quantity of organic matter is too small in most potable waters to be in itself a source of danger, whatever the quality, it might appear unnecessary to attempt either a qualitative or a quantitative analysis; but such is not the case, since from certain determinations information can be obtained which has a value in throwing some light on the source from which the organic matter is derived, and as indicating to a certain extent the origin and amount of organic pollution.

As organic matter of vegetable origin is of relatively little significance,

most of the tests applied in the analysis of water are for the purpose of attempting to differentiate between it and animal contamination. Some tests, while not professing to differentiate between the two, indicate whether the water contains any readily oxidisable matter or not. One such test consists in ascertaining the amount of oxygen the water is capable of taking up from an acid solution of potassium permanganate. Occasionally substances of mineral origin, the lower oxides of iron, nitrites and sulphides, are present which are capable of absorbing oxygen from this salt, and in this case it is necessary first to ascertain as nearly as possible how much is taken up by these substances; the remainder may then be attributed to the organic matter.

The amount of risk involved in using a water does not vary with the amount of oxidisable organic matter present; but if an excess is present, and especially if other results indicate contamination, the water must be considered unsatisfactory. One of the oldest and most difficult methods of examining the organic constituents of a potable water was devised by the late Sir E. Frankland, F.R.S. By this method the amount of carbon and nitrogen in the organic matter present in a water residue is determined and, from the relative proportions, inferences as to the character of the pollution are drawn. The process is an eudiometric one requiring great care in manipulation, and, even when conducted by those experienced in its use, the errors of experiment are considerable. It is now obsolete.

Many other processes have since been devised for approximately estimating the organic matter in water or for ascertaining its character. Attempts have been made to devise processes for detecting certain definite compounds, such as cystin, the presence of which should indicate sewage contamination. None of these has ever been generally used, and there is no doubt that most of them were useless and some misleading. The most generally useful information concerning the soluble organic matter in water can be obtained by the process, first devised by Professor Wanklyn, for estimating the so-called "albuminoid" ammonia.

Some clue to the nature or origin of the organic matter may possibly be found by this process. It gives no definite indication as to the actual amount of organic matter present, since some bodies yield all their nitrogen as ammonia, and others only an aliquot part. Albuminoid substances of animal origin contain about 17 per cent. of nitrogen, and some readily yield the whole in the form of ammonia, whilst others do not. Vegetable matters usually contain a much smaller proportion of nitrogen; hence the amount of albuminoid ammonia obtained upon the analysis of water is no indication of the actual amount of the organic substances present, and it is often impossible to say whether it is derived from a small amount of animal matter or a larger amount of vegetable matter.

It is usual to consider the free ammonia and albuminoid ammonia together, as their relative proportion is really more important than the actual quantities. The reason for this is that in all sewages and many

sewage effluents the amount of free ammonia greatly exceeds that of the albuminoid ammonia. This is well shown in the following examples :—

PARTS PER 100,000

	Nitric nitrogen.	Free ammonia.	Albuminoid ammonia.	Oxygen absorbed.
Crude sewage	0.00	5.9	2.2	5.9
Sewage effluent	2.9	1.5	0.05	0.61

In the crude sewage the free ammonia is two and a half times as great as the albuminoid ammonia, whilst in the effluent it is thirty times as great. Hence in many cases when a natural or untreated water yields more free ammonia than albuminoid ammonia, the indications are that the water is more or less polluted with sewage. There are, of course, exceptions, such as the waters derived from the Thanet Sand and Chalk of the London Basin referred to in the previous section.

Decaying vegetable matter in a water yields more albuminoid ammonia than free ammonia. For example, an infusion of dead leaves and a peaty water gave the following results on analysis :—

PARTS PER 100,000

	Free ammonia.	Albuminoid ammonia.	Oxygen absorbed.
Infusion of leaves . . . . .	.003	.031	.814
Peaty water . . . . .	.001	.024	.19

Peaty water, to which has been added 1 per cent. of the sewage and 1 per cent. of the sewage effluent just referred to, would have given the following results respectively :—

Peaty water with	Free ammonia.	Albuminoid ammonia.	Oxygen absorbed.
1 per cent. sewage	0.060	.046	.249
1 per cent. sewage effluent	0.016	.024	.20

These results would indicate sewage pollution in each case, since the free ammonia even in the second is far in excess of what is usually found in peaty waters.

Another sewage effluent, which contained thousands of coliform bacteria and other sewage organisms per cubic centimetre, gave the following results :—

Nitric nitrogen.	Free ammonia.	Albuminoid ammonia.	Oxygen absorbed.
4.44	.052	.096	.79

A mixture of this with 99 per cent. of distilled water gives a water which might be passed if judged by chemical analysis, but bacteriological examination would reveal strong evidence of excremental pollution.

Water yielding over 0.01 part per 100,000 of albuminoid ammonia, if associated with free ammonia to the extent of 0.006, must be regarded with grave suspicion. If the free ammonia reaches or exceeds 0.008 and there is no evidence of its being derived from a harmless source, manurial pollution is to be suspected, but no opinion should be given unless the history of the water and the bacteriological contents are known, for it may have been so treated as to be hygienically pure and quite wholesome. When the free ammonia is low and the albuminoid ammonia comparatively high, as in the case of peaty water, vegetable contamination is indicated, especially if the water yields this albuminoid ammonia slowly.

The whole of the organic nitrogen may be determined by Kjeldahl's process. This, though less troublesome than the eudiometric method, occupies more time and requires greater care than the estimation of the albuminoid ammonia. It is doubtless more scientific to estimate the whole of the nitrogen than a part, and, also, it is generally agreed that the nitrogen in the albuminoid ammonia bears no constant relation to the total nitrogen. Since, however, no more definite conclusions can be drawn from the total nitrogen determination than from that of the albuminoid ammonia the simpler process continues to be generally adopted.

Sewage is a most complex mixture of excremental matters and other filth dissolved and suspended in water. There is no one constituent which the chemist can ordinarily detect in water and which can be said with certainty to indicate the presence of sewage. Pollution, recent or remote, is inferred if an excessive amount of chlorides, nitrates, phosphates, ammonia, and organic matter is found in the water. These substances may, however, be derived from other and perfectly harmless sources, and, as we have seen, a small amount of sewage may be present without increasing to any appreciable extent the amount of any of these constituents. Waters which have given quite satisfactory results by chemical analysis have caused serious outbreaks of typhoid fever; whilst other waters, condemned on account of the presence of an excess of one or more of the constituents just mentioned, are used with absolute impunity. This chiefly arises from the fact that by no chemical process can it be determined whether the small amount of organic matter found in nearly all waters is of vegetable or animal origin. The organic constituents of sewage or manure may have undergone as complete oxidation as would ensue by perfect combustion in a furnace,

whereby only the innocuous mineral matter remains to indicate that the water ever was polluted. If this oxidation, or partial oxidation, has also been so fully supplemented by natural filtration that all the organisms present in the original polluting matter have been removed (but whether this is the case or not can only be ascertained by a bacteriological examination), the water must usually be considered of satisfactory quality.

In new wells constructed of brickwork on wooden curbs, the wood continues to impart a trace of organic matter to the water; the bricks also affect the water, the result being that waters from such wells are often condemned at first, but after a time the wells yield water of satisfactory quality.

The necessity of acknowledging the limitations of the information obtainable from the chemical analysis of a water is again emphasised. The chemical analysis in all its parts, the results of the bacteriological examinations, and the details of the source, must all be carefully considered in forming an opinion as to the purity and wholesomeness of a water.

Waters are frequently met with which, upon chemical examination, appear to be polluted, although the sources from which they are derived are found to be practically free from any possibility of contamination. On the other hand, waters are occasionally found of a high degree of organic purity derived from sources which must be condemned on account of the possibility of pollution. Doubtless, when such waters are examined at regular intervals by bacteriological methods, indications of pollution will sooner or later be found. As an instance, the case of a public water supply derived from the Chalk formation may be mentioned. The source was unsatisfactory on account of the presence on the collecting area of cesspits and farmyards and also a sewage-polluted river. Yet in about forty examinations the organic matter had always been so low as to cause the water to be classed amongst those of a high degree of organic purity. Bacteriologically the results were generally satisfactory, but, after a spell of wet weather, both *Bact. coli* and *Cl. welchii* were discovered in a sample. This sample gave the following results on analysis, showing that chemically it was normal and satisfactory:—

Chlorine.	Nitric nitrogen.	Free ammonia.	Albuminoid ammonia.	Oxygen absorbed.
1.05	1.29	.000	.002	.022

At the instigation of the Local Government Board,¹ Drs. Klein and Houston conducted an investigation "in order more accurately to determine in regard to water the relative value of chemical and bacterioscopic analysis simultaneously conducted—to ascertain, that is, to

¹ Report of the Medical Officer of Health. Local Government Board, 1898–9.

what extent severally chemical and bacterioscopic examination of waters purposely sewage-polluted can yield definite indications of contamination." For analysing the experimentally polluted waters two processes were chosen, which are in general use among chemists at the present day.

"Ammonia process (Wanklyn). Five hundred cubic centimetres of the polluted water were examined in the ordinary way for free and albuminoid ammonia.

"Oxygen permanganate process (Tidy, Frankland, and others). Five hundred cubic centimetres of the polluted water were dealt with, and the experiments were carried out at a temperature of 100° C. The chemical results are shown in Table I.

"In each case, 1,000 c.c. of sterile distilled water were polluted with a definite quantity of crude sewage. Of the contaminated water 500 c.c. were used for the ammonia process, and 500 c.c. for the oxygen permanganate process. In experiments 1, 2, 3, 4 the samples of sewage were obtained from a single source, and in experiment 5 from a second source, and in experiments 6, 7, 8 from a third source. In experiment 9 a natural water, known to be polluted with sewage, was selected for examination :—

TABLE I. SHOWING THE RESULTS OF THE CHEMICAL EXAMINATION OF DISTILLED WATER POLLUTED WITH VARYING AMOUNTS OF CRUDE SEWAGE PARTS PER 100,000

Exp. distilled water polluted with	Oxygen absorbed from permanganate in 1 hour at 100°C.	Free ammonia	Organic ammonia
1. 1 per cent. crude sewage, dilution 1 in 100	·3138	·0864	·0224
2. 1 per cent. crude sewage, dilution 1 in 1,000	·0848	·004	·001
3. 01 per cent. crude sewage, dilution 1 in 10,000	·0018	·0009	·0004
4. 005 per cent. crude sewage, dilution 1 in 20,000	nil	nil	nil
5. 01 per cent. crude sewage, dilution 1 in 10,000	No record	·003	·0026
6. 1·0 per cent. crude sewage, dilution 1 in 100	·1375	·0213	·0062
7. 1 per cent. crude sewage, dilution 1 in 1,000	·0326	·0021	·0006
8. 01 per cent. crude sewage, dilution 1 in 10,000	·0119	? trace	·0012
9. Thames water below Staines .	·4648	·0054	·031

"In considering from the chemical point of view the results recorded in Table I., it is to be noted that,

"Judged by the oxygen-absorbed process at 100° C., experiment 1 denotes a water of medium purity, experiment 9 a water of suspicious organic purity. The rest of the experiments denote waters varying from medium purity to great organic purity, and that,

"Judged by the ammonia process, experiments 1 and 9 denote dirty waters, experiments 2, 3, 4, 5, 7, 8 waters of great purity, while experiment 6 denotes a water organically safe.

"It must be remembered, however, that most natural waters contain more than mere traces of organic matter. Indeed, many of them contain an amount which is not far short of placing them in the class of waters of doubtful purity. Hence additional pollution in the above way might bring them from the class of waters of great purity into the class of waters which are of medium purity, or from the class of waters of medium purity into that which includes waters to be regarded with suspicion or even condemned."

In all the above waters the bacteriological analysis showed the presence of both *Bact. coli* and *Cl. welchii*. It is obvious, therefore, that no water can be said to be free from sewage pollution as the result of chemical analysis. If the detection of pollution is the object of the investigation, a bacteriological examination is imperative.

CHAPTER XIV

ANALYSES OF WATER FOR SANITARY AND OTHER PURPOSES

BEFORE commencing an analysis, one should decide on its scope and the information which should be obtained to enable an opinion to be formed.

In some cases, after the examination of the source from which a water is derived, or of the report on the source sent with the sample, a few simple tests will show whether the water is or is not suitable for domestic purposes. Usually, however, a more complete examination is necessary, involving quantitative estimations by volumetric processes, together with qualitative tests for the presence of certain objectionable substances. Many chemists are satisfied with an analysis which includes the estimation of the chlorine, the total hardness, the free and albuminoid ammonia, and tests for the presence of nitrites and nitrates. Others estimate also the nitrates and the "oxygen absorbed," and test for phosphates and objectionable metals. Others, again, make a rule of determining the total solids, since this affords a check on the results of the analysis, any large difference between the total solids and the sum of the chlorides, nitrates, carbonates and sulphates (the two latter judged from the hardness results) indicating the necessity for further examination.

The results obtained are expressed in so many different ways that the comparison of analyses by different persons is often difficult and troublesome. Thus, some express the nitrates present in terms of nitrogen, others as nitric anhydride, and others, again, as hydrogen nitrate or nitric acid. The frequent use of the word "traces" also leads to confusion, as it undoubtedly is used differently by different people. Usually it signifies "too small a quantity to be capable of determination," but often it is used merely to indicate that a small amount of the substance is present, and that this amount was not estimated. The word should be used as rarely as possible, and then only when its significance cannot be misunderstood or when followed by some quantitative qualification, such as "less than," or "approximately" a certain amount.

Again, the results may be given in grains per gallon, parts per 100,000 or parts per million, or some results may be entered in grains per gallon, and others in parts per million, in the same analysis. It is best to express all the results in the same terms, either in parts per 100,000 or parts per million. Although parts per 100,000 is mostly used in this country, parts per million would, in our opinion, be preferable, and would conform with Continental and American practice.

In the majority of cases all the information required to form an opinion upon the character of a water for domestic use can be obtained by noting its physical properties and reaction, and determining the chlorine in chlorides, the nitrogen in nitrites and nitrates, the hardness, the oxygen absorbed, and by testing for the presence of nitrites. When necessary, these can be supplemented by ascertaining the total solids or the electric conductivity, the ammonias, and applying tests for the presence of salts of iron, lead, and zinc. For the above reason we propose describing first the various methods of making these determinations, reserving for a separate chapter the description of the processes for making an analysis of the saline constituents.

The apparent simplicity of water analysis sometimes gives rise to the impression that any analyst, or even pharmacist, is competent to undertake such analyses and to interpret the results obtained. This is an erroneous impression which has caused much trouble. It is sometimes found when samples of the same water are examined in different laboratories that the analytical results vary widely.

When the results of chemical and bacteriological examinations are fairly concordant, grave differences may occur in their interpretation. Unfortunately, few analysts have the opportunity to examine a large number of sources of various kinds and study these by comparing them with the chemical and bacteriological results, and without such study the value of any report must be limited. When these discrepancies merely relate to a shallow well supplying, say, a single cottage, little harm is done, but when they refer to a large public supply matters are more serious. In one case, on receipt of an alarming report, a health authority placarded the town, advising the inhabitants of the district to boil the water from the public supply before using it for drinking purposes, and recommending them, in preference, to use water from a certain source. When the water recommended was examined, it was found to be far more impure than the public supply. In fact, the public supply was "wholesome," whereas the substitute was not certifiable as either "pure" or "wholesome."

In another case a London analyst received a sample of water which, after examination, he reported as being unfit for domestic use. His client then replied that the sample was from the public supply to a well-known health resort, and asked for "advice." The analyst came to see one of us who was thoroughly cognisant of the source of the water, and who had frequently examined samples from the mains, and always with satisfactory results. Some chemists and bacteriologists often certify samples as unsatisfactory, but rarely express an opinion upon the question of the wholesomeness of the water; and when it is a public supply we still more rarely hear of a case in which the medical officer of health is recommended to have the supply cut off, or to advertise to the inhabitants that the water is unfit to drink.

One manager of a large waterworks was so pestered by an official who was always finding fault with the water supplied to his area,

that he informed him that unless he got a definite report from him that the water was unwholesome he should ignore his letters, and that if he certified that it was unwholesome, he would immediately cut off the supply from his district. This put an end to the pin-pricks. When an authority wants to take over a supply from a company, it is not unknown to have the most frivolous complaints made to the company, under the impression that the more complaints made, the cheaper the rate at which they will be able to purchase the undertaking.

It is only in a very few cases that an opinion upon the wholesomeness of a water can be given without some chemical analysis in addition to the bacteriological examination, but where water from the same source is being kept under observation and examinations made at regular intervals, and when expense has to be considered, it is in some cases preferable to have all samples bacteriologically examined, and only an occasional chemical analysis made. There is a range of variation in the waters from all sources; this is usually very small, but in some cases it is considerable. With a very variable water more frequent analyses are desirable than with the less variable.

A person who undertakes an analysis should be prepared to express an opinion as to whether the water is (a) pure, (b) wholesome, (c) suitable for domestic purposes; and in most cases, in order to do this, he must know something of the source from which the water was obtained. In a few cases the analytical results may be so unfavourable that an opinion may be given in ignorance of the source, but in the majority of samples of water submitted for analysis the water cannot be definitely classified without some knowledge of the place of origin and the history of the water.

It is not always necessary to make a complete chemical and bacteriological examination of a water, but we are of opinion that there are very few instances in which it is not necessary to make a bacteriological examination for the presence of *Bact. coli* and to determine its relative abundance, especially if the object is to determine whether the water is pure and wholesome and suitable for domestic use.

In other cases the nature of the examination will depend upon the purpose for which it is intended to use the water, and should be carefully thought out before the analysis is commenced. The conclusion arrived at by the "Copper and Brass Extended Uses Council" shows the trouble engineers experience in dealing with analysts' reports. After collecting analyses from practically every water authority of any importance in the kingdom, they stated: "Another impression received from the perusal of the information so gained is that of the great need for some common form in which the analysis of water can be expressed. Analyses have been received in almost as many forms as there are different water supplies, due, of course, mainly to the very many differences in the natural product, which set the analyst a particularly difficult problem. Still, it is surprising to find the facts expressed in so many different ways.

"When we come to the bacteriological analysis, even greater

divergence exists in the form in which the results are presented. It is clear that an inestimable boon would be conferred upon the community if some common method could be found for the interpretation of these results, and some standard for their representation." A good deal has been done in this direction, and some standardisation achieved, as a result of the reports issued by the Ministry of Health on Sewage Analysis, and the Bacteriological Examination of Waters, but there is still much to be desired, particularly in respect of the chemical analysis of waters.

At the end of this chapter there will be found a specimen of the ordinary water analysis report sheet used in our laboratories.

Of far more serious importance are the actual discrepancies in the analytical results. So long as these exist, standards for their expression are useless. The above Council could scarcely expect to obtain, from any ordinary analysis for public health purposes, information such as they required for determining the action of different waters upon copper, lead, and iron pipes. The information required could only have been obtained by special analyses. This emphasises the view we have already expressed, that the scope of the analysis will depend not only upon the source of the water but also upon the object for which the analysis is required.

Ref. No.....

ANALYSIS OF A SAMPLE OF WATER *received on*.....*from*.....*Labelled*.......... *Date*.....*Taken by*..... *Witness*..... *Signed*.....

CHEMICAL RESULTS IN PARTS PER 100,000

Appearance

Turbidity (Silica Scale)

Colour (Hazen Scale) Odour.....

Reaction pH..... Free Carbonic Acid.....

Electric Conductivity at 20° C..... Total Solids, dried at 180° C.....

Chlorine in Chlorides..... Alkalinity as Calcium Carbonate.....

Hardness : Total..... Temporary.....Permanent

Nitrogen in Nitrates..... Nitrites

Free Ammonia..... Ammoniacal Nitrogen

Albuminoid Ammonia..... Albuminoid Nitrogen

Oxygen Absorbed in 4 hrs. at 26.7° C.....

Metals

" Free Chlorine ".....

Etc.

BACTERIOLOGICAL RESULTS

Number of Bacteria growing on Agar per cc. or ml. in 1 day at 37° C.....

" " " " " cc. or ml. in 2 days at 37° C.

" " " " " cc. or ml. in 3 days at 20° C.

Presumptive Coli Reaction..... Present in Absent in

Bact. Coli Present in Absent in

Cl. Welchii..... Present in Absent in

Report :

Date.....*Signature*.....

PART V

ANALYTICAL PROCESSES AND METHODS OF EXAMINATION

CHAPTER XV

COLLECTION OF SAMPLES OF WATER

THE quantity required for examination will vary according to the information required. Where it is merely desired to make a so-called chemical analysis a litre is sufficient, provided no accident occurs during the carrying out of the processes. For most purposes 2 litres are advisable, and allow a margin for contingencies. The ordinary stoppered Winchester of colourless or pale green glass holds this quantity, and serves very well. Dark-coloured bottles are to be avoided. Strong colourless glass bottles of two sizes, 1-litre and 2-litre respectively, are generally useful. The bottles should be used for no other purpose, and before use be rinsed with strong acid, then with water to remove all traces of acid, and finally with distilled water. For carrying about and sending by rail, stout wicker-work cases or wooden boxes lined with felt, in which the bottles stand upright, are the safest and best. These can easily be made so as to be secured with a padlock if desired. Where large quantities of water are required for experimental purposes, acid carboys are very useful. They hold about 50 litres.

Wherever possible the bottle should be rinsed out two or three times with the water to be examined before being finally filled. If this cannot be done the bottle should be well drained. The stopper should not be laid down, but kept contained in its covering in the hand before being reinserted. The bottle should not be entirely filled; a small amount of air should be left in it. If it is completely filled, and the stopper firmly inserted, any increase in temperature will cause the neck of the bottle to crack,

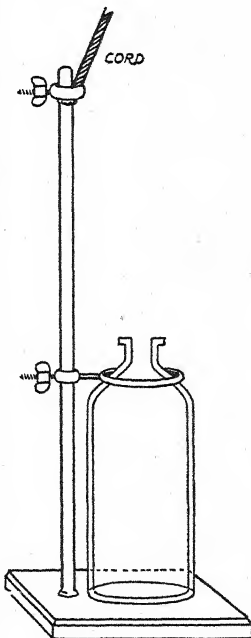


FIG. 5.

and a decrease of temperature usually wedges in the stopper so tightly that it is difficult to remove it without a fracture.

Unless it is absolutely unavoidable, no funnel or jug should be used in filling the bottle, and the bottle should be so held that the water does not come in contact with the hand before entering.

In taking a sample from a tap or pump, the nozzle should first be examined to see that it is clean. If not, it should be cleaned and then heated strongly by the flame of a blow-lamp or spirit lamp. Water should then be allowed to run to waste for a few minutes before filling the bottle, unless it is desired to ascertain whether the water is affected

by standing in the mains or pump pipe. If such is the case, it is best to take the sample first thing in the morning, before any has been drawn for other purposes. In taking samples from springs and rivulets it is often necessary to make an excavation sufficiently large to hold the hand and bottle, and allow sufficient time for all matter disturbed to be washed away before taking the sample. Where the sample must be taken by immersing the bottle, as in ponds, cisterns, reservoirs, rivers, many wells, etc., it is generally quite satisfactory if the bottle is fixed to a clean retort-stand (Fig. 5) and sunk rapidly to the required depth.

The apparatus shown in Fig. 6 is very easily put together, and can be used with equal facility for obtaining water from a considerable depth in a bore tube or well, and from an open tank or running stream.

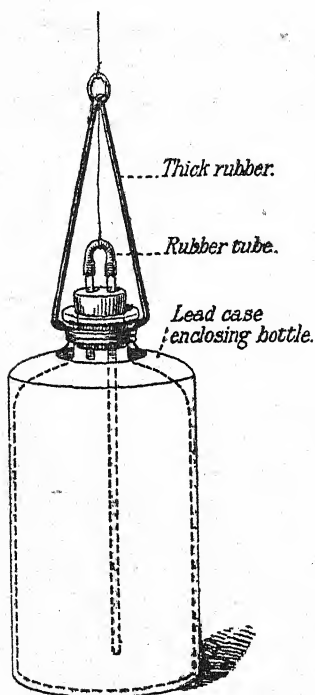


FIG. 6.

the other a longer piece of tubing reaching to near the bottom of the bottle, and projecting about an inch above the rubber stopper. The projecting tubes are connected by a piece of rubber tubing about 2 inches long. The bottle is suspended by means of a stout band of rubber about 1 foot long, such as is used for door springs, the free ends being secured tightly to the neck of the bottle by cord or catgut. A metal loop or swivel connects the rubber suspender with the cord or catgut used for lowering the bottle into the water. The loop or swivel is connected with the short piece of rubber tubing uniting the two glass tubes by a piece of string or catgut, of such length that, when the bottle is suspended, there is no pull upon the rubber tube, which, however, can easily be jerked off when a sharp pull is given to the suspending cord. The apparatus being arranged, it is lowered to the required depth; a sharp jerk is then given to the suspending cord, when

the rubber tube is detached. Water enters through the longer tube and the air is expelled through the shorter tube. Bubbles of air can be seen or heard rising through the water until the bottle is full, or until only a little compressed air remains in the neck of the bottle. As the apparatus is raised, the air thus imprisoned expands and prevents water from nearer the surface entering. Catgut or copper wire serves better than cord for suspending the bottle, and if this is marked off in yards the depth to which the bottle has descended is known.

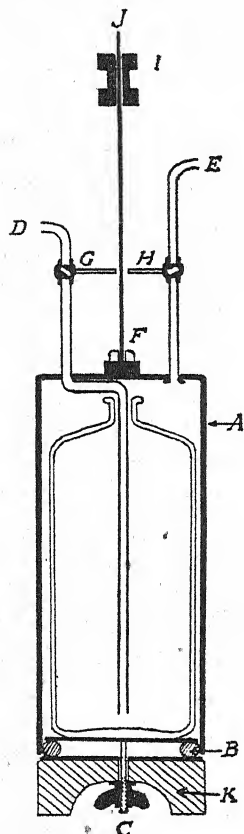


FIG. 7A.

The points requiring chief attention are to see that the rubber stopper is tightly inserted, and that the small piece of rubber tubing can be easily detached by a slight jerk.

Although this apparatus is generally useful, it cannot be used when a sample has to be taken from a depth of 300 feet or more below the surface of the water. The pressure is there so great that the bottle is crushed in, the explosion sounding like the discharge of a gun in the well. To get over this difficulty a special apparatus¹ was made, and is illustrated in Fig. 7A.

A is a heavy copper cylinder 5 inches in diameter and 10 inches in length and able to contain a bottle of sufficient capacity to permit of a chemical and bacteriological examination of a sample of water being carried out.

The cylinder is sealed at the top, through

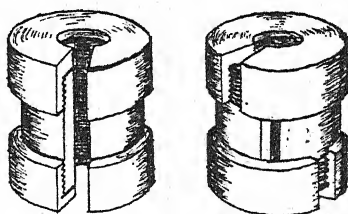


FIG. 7B. · Reproduction of weight I.

which pass two tubes D and E, the former continuing to the bottom of the container and the latter just passing through the top. These tubes are fitted with long-handled taps, G and H. The taps are closed when the handles are in the horizontal position, and opened when they are depressed.

The bottom of the container is closed by an expanding rubber seal B, which is fixed and released by the screw C, and is weighted by the lead K (1 inch depth).

The bottom being removable permits the insertion of the bottles, and the cleansing of the interior of the apparatus.

¹ Apparatus made for us by Messrs. Casella, Fitzroy Square, London, W.1.

The apparatus is suspended by a cord or wire J of suitable strength, which is attached to the top of the container at F where a rubber cushion is fixed.

The weight I is slotted so that it can be threaded on to the cord J along its length when the apparatus is lowered down the well (see illustration).

For the collection of a sample of water, the sterilised apparatus complete with sterile bottle is lowered down the well, and at the required depth the weight is placed in position on the cord and released. On reaching the apparatus, the weight opens the taps by depressing the handles and water enters at D, while the air escapes at the higher level at E.

The weight comes to rest on the rubber cushion, which lightens the blow on the apparatus.

When air bubbles cease to rise (this takes several minutes), the apparatus is withdrawn, and the sample removed by turning the screw C and releasing the bottom of the container.

The bottle is completely filled with water at the required depth, and no water enters on withdrawing the apparatus from the well.

The stopper, which during collection has been kept in a sterilised cloth, is now inserted.

By attaching a nozzle to the steam tap from a pressure boiler, the whole apparatus can be sterilised in a few minutes by the current of high-pressure steam.

The apparatus can be used in a boring of 6 inches diameter. A smaller size would be required for tubes of lesser diameter.

The following expedient is sometimes used when a special sinking apparatus is not available. Cord is tied round the neck of a weighted bottle, and then, at a distance of 2 or 3 inches, a loop is passed round the base of the stopper. The stopper is tightly inserted and the bottle suspended by the stopper. When the bottle has been sunk to the requisite depth, a sharp jerk on the cord should pull out the stopper and the bottle fills with water. It is not always successful, especially if the bottle is sunk to any considerable depth.

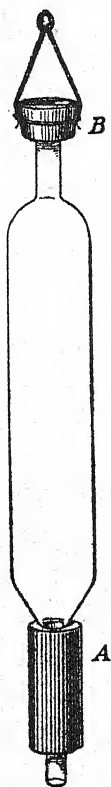


FIG. 8.

Occasionally, water has to be obtained from 2-inch tubes driven for experimental purposes. In such cases the apparatus shown in Fig. 8, and made out of a 200 or 250-c.c. pipette, answers very well. A is a piece of lead pipe sufficiently heavy to sink the pipette. B is a perforated rubber stopper fitted on the upper end of the pipette and covered with a narrow strip of oiled silk. This is secured by a string tied tightly round the stopper, and a loop should be left so that the apparatus can be attached to a cord. When the tube is lowered, the water enters, displacing the air through the oiled-silk valve. When the

tube is raised, the pressure on this valve closes it securely and prevents the water escaping.

When a water has to be examined bacteriologically, special precautions must be taken to prevent the slightest risk of contamination. If collected in bottles, these should be small (250 to 300 c.c. capacity¹) and cleansed by rinsing first with strong sulphuric acid, then with water until all acid is removed, then with distilled water, and finally sterilised in the autoclave maintained at a pressure of at least 15 lb. per square inch for thirty minutes. The stoppers must be relaxed by an intervening strip of paper to prevent fracture of the bottles during sterilisation. They are then allowed to cool in the steriliser, the stoppers allowed to fall into place by carefully removing the strip of paper with sterilised forceps, and tied down with a covering of sterilised parchment paper or selected fabric. A bottle that we have found suitable in certain cases for the collection of samples of water for

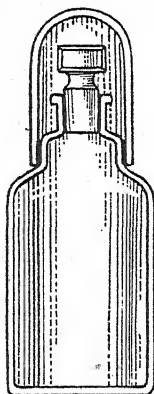


FIG. 9.

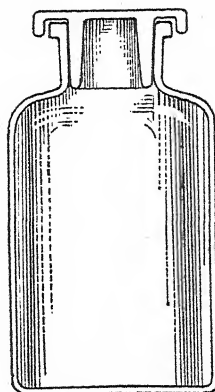


FIG. 10.

bacteriological examination is one known as the ether bottle, and is illustrated in Fig. 9. It has a glass hood which covers and protects from dust the stopper and neck of the bottle. The whole can be sterilised in the autoclave, but the bottle has the disadvantages of being easily fractured and possessing a narrow neck. Special samples are sometimes collected in small sterile tubes, pipettes or flasks. The bottle we find most generally useful for collecting samples of water for bacteriological examination is of approximately 300 c.c. capacity and has a wide neck with a ground-glass stopper, the rim of which overlaps that of the bottle. It is illustrated in Fig. 10.

The sterilised and covered bottles should be carefully protected until used, and on no account should they be opened until required for the collection of samples. Where it is required to ascertain the bacterial condition of a chlorinated water at a certain point of treatment or distribution it is necessary that the sample should be dechlorinated in

¹ Occasionally a litre or more of water is required.

the bottle at the moment of collection, otherwise any free chlorine or chloramines present would continue to exert a sterilising action during transit of the sample to the laboratory.

A longer "contact time" might thus be given than is allowed in practice, leading to false and unduly favourable results in the bacteriological examination.

In such cases, bottles should be used in which a minute crystal of sodium thiosulphate has been added before sterilisation.

Too great care cannot be exercised in the collection of samples of water for analysis, especially as regards the bacteriological examination. The access to the sample of a speck of dirt, or the touching of the inner side of the stopper with the fingers or placing the stopper on the ground or other surface may be responsible for completely false results.

Whenever possible it is desirable for the analyst or bacteriologist to collect the samples himself, and in other cases he should be asked to supply the necessary bottles. Samples sent otherwise are frequently inadequate in quantity and unsuitable in other respects.

When application is made for bottles it is advisable to state precisely the purposes for which they are required.

In the collection of bacteriological samples the bottles must not be rinsed out or otherwise interfered with, since they are prepared for direct use on dispatch from the laboratories.

The first matter to consider is the selection of the sampling point, and great care and discretion are necessary in this selection in order that the sample shall represent as fairly as possible the supply which it is desired to examine. In our investigations of water supplies on which unsatisfactory reports on samples have been issued, we have found that a significant proportion of these adverse reports was due to the selection of unsuitable sampling points or errors in the method of collection of the samples. This is particularly prevalent in the collection of samples from public water supplies when it is required to ascertain the purity of the water delivered to consumers. Kitchen or scullery taps, often defective, or dirty with much slime in the nozzle, or fed from an uncovered house cistern which is seldom, if ever, cleaned out, are favoured points of selection. Such samples frequently yield amazingly bad bacteriological results which have no relation to the water supply delivered to the premises.

If it is desired to ascertain the purity of the public water supply, and not the uncleanness of the cistern or tap, it should first be ascertained that the tap is fed directly from the main, and the shorter and less complicated the service pipe the better. It should also be ascertained that the water in the domestic pipe is not warmed by close proximity to the hot-water system, and a knowledge of the metal of which the pipe is constructed is sometimes of value. Thus, traces of copper in the sample exert a slow bactericidal action, and it is not uncommon for new domestic copper installations to impart traces of that metal to the water.

The tap should not have a defective washer, allow water to escape

between the spindle and the gland, nor be equipped with any anti-splash or other attachment, and have no adjacent connections to such domestic apparatus as geysers, water-softeners, etc. It should not be too large a tap, and the delivery of water from the nozzle should be reasonably uniform.

The suitability of the tap having been decided, it should be thoroughly cleansed, both on the outside and the inside of the nozzle. The water should then be allowed to run to waste for several minutes in order to free the service pipe of stagnant water, the period of time allowed depending on the length of the service pipe. The tap is then turned off and sterilised by flaming with a blow-lamp, or cotton-wool impregnated with methylated spirits and held by forceps. This flaming should be thoroughly carried out until the tap is unbearably hot, when it is carefully turned on to deliver a steady stream of water. After the tap has cooled, the sample should be collected with care and expediency.

The stopper of the bottle should be retained in its covering and not allowed to come in contact with the fingers or any other surface, nor must the neck of the bottle be touched by the hand. Care should be taken in draughts or winds, since dust might then be blown into the sample. The bottle should be filled with the water, the stopper replaced and tied down with its original covering, and, the bottle, after labelling, replaced in the ice-case for immediate dispatch to the laboratory.

A specimen of the label which we find suitable for water samples is shown below.

SAMPLE OF WATER

Submitted for Examination
(State the examination required, e.g., Chemical, Mineral Constituents, Bacteriological, etc.)

by
(Name of authority or person requiring the examination)

of
(Address of authority or person)

Taken from
(State point and place where sample was taken, together with source, if possible)

.....
.....

at on
(Time of sampling) (Date)

by
(Name of person taking sample)

in the presence of

Signed
Dispatch Sample as soon as possible after taking and notify the Laboratories.

The period of time elapsing between the collection of the sample and its receipt at the laboratory should be as short as possible. If the weather is cold and the sample can be received for examination within an hour or two of collection, ice need not be included in the case. In other circumstances it is necessary to insert ice in the container of the case otherwise the temperature of the sample may rise unduly and lead to fallacious results on examination. "Cardice" (solid CO_2) is sometimes used for this purpose, but too much should not be added to the case, otherwise the cold produced is so intense that fracture of the bottles takes place.

For the collection of samples at waterworks it is customary to instal special sampling taps at appropriate points, and a specimen of such a tap is illustrated in Fig. 11.

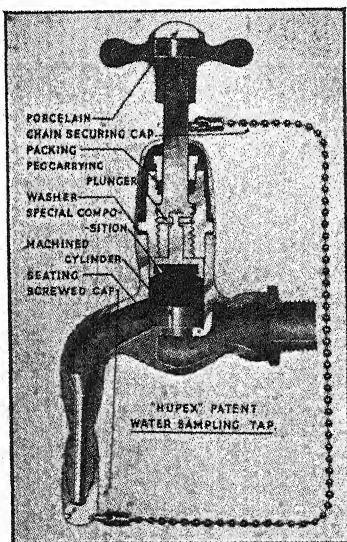


FIG. 11.

SPECIAL FEATURES

1. Plunger of semi-vulcanised rubber compound on which bacteria will not feed, as in the case of leather washers.
2. Plunger unaffected if tap heated for sterilisation purposes. Leather or fibre washers are burnt up.
3. Smooth machined cylinder walls, free from pockets. The interior of an ordinary tap is rough and allows dirt to collect and bacteria to breed.
4. Close fitting screwed cap to prevent bacteria entering the bib.
5. Bacteriological samples can be contaminated by splashing while sampling. The stream-line jet, as illustrated, eliminates this.
6. The screwed cap is fitted with a chain to prevent loss.

Such taps could well be installed at various selected and agreed points on the distribution mains of public water supplies as "official sampling points," and thus avoid a good deal of the unnecessary annoyance and wasted effort which result from the collection of samples from unsuitable taps or hydrants. Street hydrants are seldom satisfactory sampling points on account of their size, the impossibility of adequate cleansing and sterilisation, and the disturbance of mains' silt which often takes place when a hydrant is opened.

The collection of bacteriological samples is to be regarded as of the character of a surgical operation with the observance of similar aseptic precautions, and it should be carried out only by those who have been competently instructed.

At the end of this chapter there will be found a copy of the instructions that we enclose with each sample bottle, and it cannot be too

often emphasised that the reliability of the analyses and their interpretation depend largely on a correct manner of collection of the sample.

When the gases contained in a water have to be determined, special care must be exercised in collecting the samples. Usually these are taken in the special tubes or flasks which will be used for the determinations. When the water is being taken from a tap, a piece of tube should be connected to the nozzle and the water allowed to enter at the bottom of the flask, and the flow continued until a good deal has run to waste. Whilst the water is still flowing the bottle can be slowly withdrawn and the stopper inserted. When the water has to be taken from a tank, stream, or well, the following device (Fig. 12) of Mr. Phelps may be used. Two wide-mouthed bottles are required, one of not less than twice the capacity of the other. Both are fitted with doubly-perforated rubber stoppers, through one hole of which a glass tube passes to the bottom of the bottle and another just projects through the stopper. The bottles may be placed side by side or the smaller one may be placed below the larger. The long tube of the larger bottle is connected by a piece of stout rubber tubing with the short tube of the smaller bottle. When the bottles are weighted and sunk, water begins to flow into the smaller bottle, air escaping from the larger. When sunk to the proper depth and allowed to rest for a few minutes, or until air bubbles cease to rise, both bottles are full of water, but that in the smaller bottle will not have been in contact with air. When they are withdrawn, a solid stopper must be inserted in the smaller bottle. Mr. Phelps says that, "although devised primarily for the collection of samples for the 'oxygen dissolved' determination, the apparatus may be used for a variety of purposes." Casella's apparatus¹ is now generally used in the place of this device.

Bottles in which samples are collected should be capped with clean washleather, parchment paper, or linen, and duly labelled to ensure identification. If such identity has afterwards to be proved, the string or tape securing the covering should be so sealed that the bottles cannot be opened without breaking the seal.

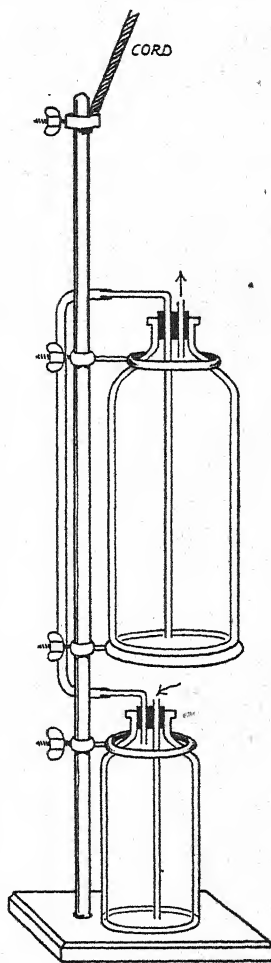


FIG. 12.

¹ Manufactured by Messrs. Casella, Fitzroy Square, London, W.1.

Care should be taken to record on the spot every detail which may have any bearing upon the results of the analyses to be undertaken, or which may be of importance in connection with the taking of the samples, or be of general or scientific interest.

In taking a sample from a stream, the following points should be recorded :—

1. Date and time when sample is taken.
2. In whose presence.
3. Exact point marked on Ordnance map.
4. Whether at or near middle or side, and which side.
5. Depth below surface.
6. Weather at the time, and particulars of any recent rainfall.
7. Whether the level of water is above or below average.
8. Observations with reference to any possible sources of pollution in the vicinity.

9. Signature of person taking sample.

If a single sample only is being taken, it should be collected from beneath the surface near the middle of the stream.

In taking samples from an open well, record 1, 2, 3, as above, and, if possible, in addition—

4. Approximate ground surface level above O.D.
5. Depth from ground level to surface of water.
6. Depth of water in well, and depth at which sample is taken.
7. The mode of construction of the well, including its covering.
8. Whether the appearance of the water is affected by heavy rains.
9. Any indication of pollution, discoloration of sides, etc.
10. Character of the surroundings, proximity to drains, sewers, stables, dustbins, piggeries, churchyard, etc.
11. When available, a section of the well, and
12. Yield of water and effect of pumping.

As the character of the water in open wells often varies at different depths, it is best to lower the bottle rather rapidly under the surface of the water, so that it may, when filled, contain water from all parts of the well.

In taking samples from a large reservoir, one should be taken near the point of entry, and another near the exit of the water. If only one sample is to be collected, it is best to take it from beneath the surface, just over or very near the mouth of the trunk main or conduit. The installation of suitable sampling taps on the inlet and outlet mains of reservoirs is advisable when possible.

When taking a sample from a house-tap connected with a public supply, it should always be noted whether the tap is directly connected with the main or with a cistern. If the latter, the cistern should be examined and particulars thereof recorded. The position of the main should also be noted, and the proximity to a dead-end or ball hydrant ascertained if possible.

If there is any suspicion that the water is acting upon the service pipes, the material of the pipes and the length traversed by the water

should be recorded. One sample should be the first drawn off in the morning and another drawn after a quantity of water has been run to waste. Special investigations and sampling methods are necessary when the question of plumbo-solvency is under consideration.

When samples of water are received for analysis, and there is any doubt about the way in which they have been collected or about the cleanliness of the bottles used, or when the samples are sent in bottles closed with unclean corks, it is best to communicate with the sender and offer to dispatch suitable bottles for fresh samples. The following form employed by us is generally useful, the sender of the sample being requested to furnish the information required.

PARTICULARS REQUIRED CONCERNING SOURCE, ETC., OF WATER
SENT FOR ANALYSIS

1. Name and address of person desiring the analysis.
2. Is a chemical or bacteriological examination required, or both ?
3. Reasons for wishing an analysis—if the water is suspected of causing ill-health, the symptoms should be stated.
4. Exact place from which the sample was taken. If from a house-tap, say whether drawn through a cistern or directly from the main.
5. State whether a well, spring, or stream, or a public supply.
6. If a well, state the depth, and whether newly constructed.
7. Whether the bricks are set dry or in cement, or are cement-lined or puddled behind.
8. State nature of subsoil from which water is derived.
9. State whether there are any drains or cesspools, or other possible sources of pollution, and distance from source of water.
10. Does the water become affected in appearance, odour, or taste, after a heavy rain ?
11. Date on which sample was taken and sent.

When sending a sample of water for analysis, the above form should be filled in and returned.

Suitable bottles, cleansed, sterilised and ready for filling, will be sent on application.

In filling the bottles, carefully carry out the instructions given for collecting the sample of water.

Samples should be dispatched immediately after being collected, and bacteriological samples should, in warm weather, be packed in ice. Special boxes for the purpose will be sent when required.

To this form are attached the following directions for securing the proper collection of the samples of water :—

INSTRUCTIONS FOR COLLECTING SAMPLES OF WATER FOR
ANALYSIS

1. The water should be collected in white glass bottles having well-fitted glass stoppers. Bottles holding about $\frac{1}{2}$ gallon of water are necessary for the chemical analysis. Smaller quantities are sufficient for the bacteriological examination.

2. When the bottles have been forwarded from the laboratories, it is unnecessary to rinse these before taking the sample of water ; the removal of the stoppers and filling direct is all that is required. In the case of clients using their own bottles, these should be thoroughly cleansed, filled thrice with water, and thrice emptied, before collecting the sample.

3. In collecting from a pipe, the tap should be turned on and the water allowed to run to waste for at least two minutes (timed by a watch) before the sample is taken, in order to prevent impurities in the pipe being collected in the specimen. If a bacteriological analysis is to be conducted, the nozzle of the tap should be flamed (*i.e.*, by dipping a small piece of cotton wool in methylated spirit, lighting same, and holding the wool, by means of forceps, close to the nozzle until the whole tap is unbearably hot) and then cooled by the running water before the bottle is filled.

4. In collecting from a stream, lake, spring or well direct, the stopper should be kept inserted in the bottle and the whole bottle placed well under the surface of the water, the stopper removed by means of a clean piece of string, and the bottle filled. This method prevents the inclusion of dust which may have settled on the surface.

5. In collecting the samples, hold the bottle with the hand as far away from its neck as possible. On no account should the water ever come in contact with the hand.

6. The stopper should finally be secured by capping with a piece of clean linen or parchment paper.

7. After stoppering, the bottles should be labelled, stating the source, date, and time of collection. It is generally desirable to fill in all the particulars in the blank spaces of the labels supplied with bottles from the laboratory.

When the water is derived from a deep well, the following details should be obtained, if possible, as records of such are of permanent value :—

PARTICULARS RELATING TO THE SOURCE FROM WHICH THE WATER
WAS DERIVED

Information supplied by.

Date.

Position of well, 1-inch Ordnance map.

Ground level at well,

Depth from ground level to surface of water (rest level).

Section of well.

Surroundings likely to affect the character of purity of the water.

If the water varies in appearance or character, state under what circumstances.

Approximate yield of well.

Occasionally further inquiries have to be made to enable a reliable opinion upon some point to be given. The nature of these inquiries will depend upon the source, and may be inferred from a consideration of the sections referring to the examination of the various sources from which water supplies are derived.

Report No. 71, entitled "The Bacteriological Examination of Water Supplies," issued by the Ministry of Health, and obtainable from H.M. Stationery Offices, should be consulted by all whose duties include the collection of samples of water for analysis.

CHAPTER XVI

PHYSICAL EXAMINATION

Electric Conductivity of Water. The determination of the E.C. at 20° C. will probably become a matter of routine with analysts, since the results are a very useful check on the chemical analysis, and often save the estimation of the "total solids."

It has already been stated that the electrical conductivity of any sample of water depends upon the electrolytes dissolved in it, and, providing the solution is very dilute, the conductivity is proportional to the amount of such substances dissolved in the water. Unfortunately, the determination of the conductivity tells us nothing as to the nature of the substance in solution, but if this increases or decreases in amount, so does the conductivity increase and decrease, and if the conductivity of a water is ascertained, then any change in the character of the water will be indicated by a change in the conductivity.

Fig. 18 illustrates an apparatus for determining conductivity known as the "Dionic Water Tester."¹ The component part shown on the left-hand side of the illustration consists of a glass cell which carries the water to be tested. The component on the right is the conductivity meter which consists of a hand-operated dynamo and a galvanometer. The cell is filled, by way of the raised cup, with the sample of water, a little being allowed to run to waste at the overflow. A reading of the temperature of the water is then taken on the thermometer, and, depending on this temperature, the adjustable electrode of the cell is moved to the appropriate point on the scale shown. This adjustment automatically corrects the conductivity figure read to that which would be obtained at 20° C., and the temperature range which can be thus allowed for is 10° C. to 40° C.

Operation of the dynamo now generates a current through the cell and galvanometer and a direct reading of the conductivity of the water is obtained on the scale. The conductivity meters are fitted with single or multi-scales having a variety of ranges up to 20,000 units. The unit of conductivity adopted is the reciprocal of 1 megohm per centimetre-cube.

In making distilled water the apparatus is invaluable, and Tables I. and II. on p. 200 show the reasons for preparing such water with the greatest care.

The water used was a roof-collected rain water. The water was distilled in a copper vessel with tinned copper condensers, and 3½ litres

¹ Manufactured by Messrs. Evershed and Vignoles, Acton Lane Works, Chiswick, London, W.4.

were placed in the still and each successive 250 c.c. of distillate examined. In the first experiment (Table I.) nothing was added to the water before distillation, and in the second (Table II.) the water

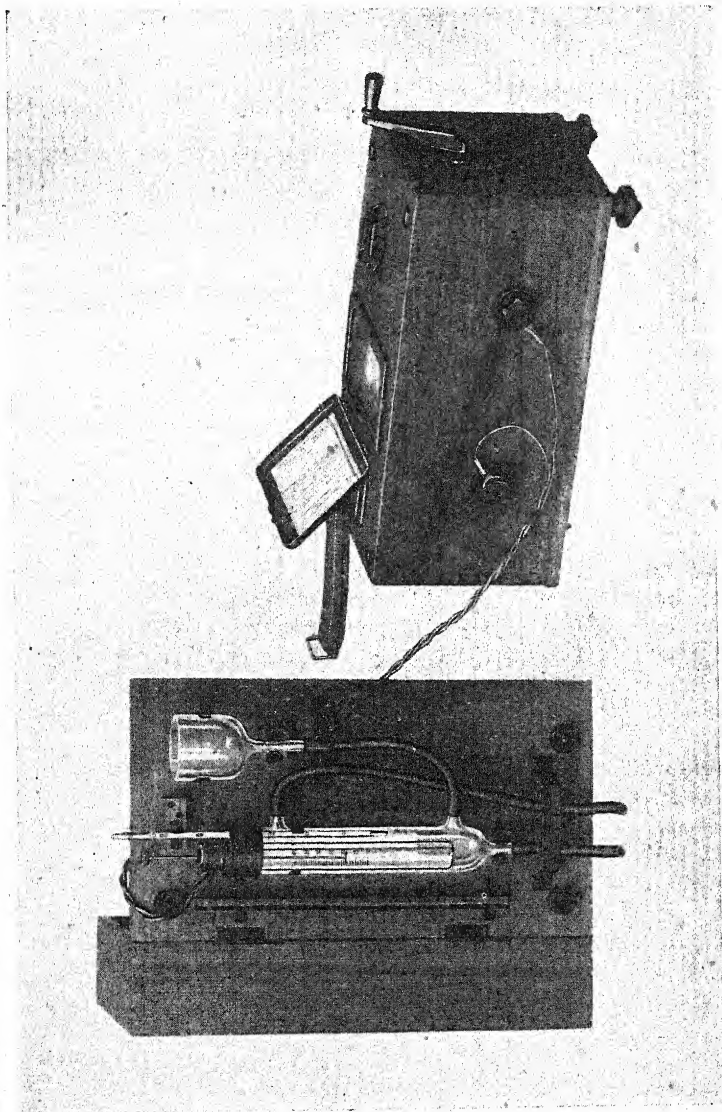


FIG. 13.

was neutralised with dilute sulphuric acid. The hardness of the water was about 7 parts per 100,000, and it contained 0.15 part of free carbonic acid and 5.1 parts of calcium carbonate as bicarbonate.

TABLE I.

Parts per 100,000.

TABLE II.

No. of 250 c.c.	E.C. at 20°C.	Free ammonia.	Free CO ₂ .	E.C. at 20°C.	Free ammonia.	Free CO ₂ .
1 . . .	8.7	0.035	5.2	11.7	0.01	9.0
2 . . .	5.5	0.003	2.5	4.2	0.01	1.1
3 . . .	4.2	0.001	1.7	3.4	0.001	1.0
4 . . .	3.6	None.	1.5	2.4	0.001	0.5
5 . . .	3.3	"	1.0	2.3	None.	0.4
6 . . .	3.1	"	0.8	2.2	"	0.3
7 . . .	2.3	"	0.5	2.2	"	0.2
8 . . .	2.2	"	0.45	1.8	"	0.175
9 . . .	1.9	"	0.4	1.8	"	0.16
10-12 . .	1.6	"	0.25	1.5	"	0.15

From the table given on p. 150 it will have been noted that the E.C. varies with any change in the quality or quantity of the constituents, and when the E.C. for a water has been ascertained, any change in this value indicates the necessity of a search for the cause, especially if the change is marked. Similarly if it is found that the

value of $\frac{\text{E.C.}}{\text{total solids}}$ has also changed the reason for this should be sought. If this ratio remains constant, the inference is that the change in the value of E.C. is a quantitative rather than a qualitative one.

The value $\frac{\text{E.C.}}{\text{T.S.}}$ with potable waters appears to vary from 11 to 18, as shown in the table on p. 150.

A development of the Dionic Water Tester is the Dionic Water Meter. This is a permanently fixed apparatus which automatically provides a continuous indication and record of the amount of inorganic impurity present in any dilute solution. Its value to many waterworks and industries in the control of materials, plant, and processes is obvious, and considerable information and saving of labour are obtained by the use of this device. An electrical supply is necessary for the apparatus.

The Colour of Water. Usually it suffices to record that the "colour is normal" when the water, viewed in a colourless glass cylinder about 25 cm. long, by light reflected from a dead white surface, is very faintly green or bluish-green, approaching that of distilled water. With a little experience, it is not necessary to compare with a similar tube filled with distilled water. If the water is yellow-green, yellow or yellowish-brown, this should be stated and qualified as follows:—

Very slight : Requiring a skilled observer to detect.

Slight : Just noticeable when looked for by any ordinary individual.

Distinct : When noticeable by any observer.

Decided : Too noticeable to be agreeable.

Very marked : When quite unsightly and objectionable.

These terms may be used for other observations, as of turbidity, odour, etc.

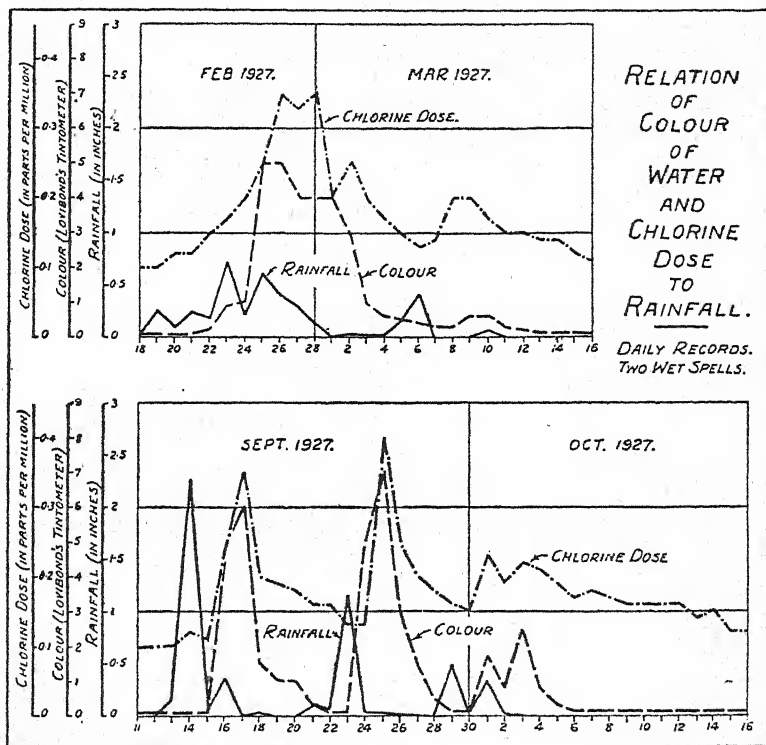
When the water is sufficiently turbid to affect the colour, filtration

must be resorted to, unless it is stated that the colour recorded is of the water as received or the colour of the unfiltered water. As a rule, it suffices to record the tint of the unfiltered water.

For comparative purposes it is often advisable to keep records of the colour, since the colour is, to a certain extent, an index of the organic impurity, although not entirely reliable.

It has, however, been found possible at a waterworks with which we are concerned to correlate the colour and impurity of the water as regards its power to absorb chlorine. After heavy rainfall the water

TABLE III



is subject to occasional sudden and wide variation, which necessitates increase of chlorine dosage in order to leave a residual to effect sterilisation. The required dosage is controlled by colour determinations with the Lovibond Tintometer. Examples of the results obtained at these works are shown in Table III.

A simple method of approximately estimating the colour is by the use of a solution of potassium bichromate and cobalt sulphate (*vide* formula), or by use of the A.P.H.A. (Hazen) solution, *i.e.*, potassium-platinic chloride and cobalt chloride. (*Vide* formula in Appendix.)

A pair of colourless glass tubes with flat bottoms are required. Tubes about 26 cm. high and holding about 250 c.c. are most generally

useful. One is filled with the water to be examined, which must be filtered if in the slightest degree turbid, and the other nearly filled with distilled water. Into the latter, one or other of the above coloured solutions is added until the colour corresponds to that of the water being examined. The amount of coloured solution added and the total volume of distilled water being known, the dilution gives the degree of colour, *i.e.*, the percentage of colour solution used.

In America, standard solutions are kept in 100-c.c. Nessler tubes and used as required. The procedure recommended is described as follows :—

“The colour of a sample shall be observed by filling a standard Nessler tube to the height equal to that in the standard tubes with the water to be examined and by comparing it with the standards. The observation shall be made by looking vertically downwards through the tubes upon a white surface placed at such an angle that light is reflected upwards through the column of liquid. Waters having a darker colour than 70 shall be diluted before making the comparison, in order that no difficulties may arise in matching the hues.”

If a turbid liquid is thus examined, this is called the “apparent colour,” but such a determination is really useless, since it never matches that of the standard.

In any report, the standard adopted should be stated.

Burgess¹ designed a special instrument for colour estimation. It consists of two horizontal tubes, each 2 feet long, one of which is filled with distilled water, and the other with the water to be examined. In a black box at one end of the tubes is a mirror, placed at an angle of 45 degrees and reflecting light transmitted by the tubes upwards through two cylindrical glasses, one of which, that belonging to the tube containing the water being examined, contains a little distilled water, and the other the yellow-brown solution of potassium bichromate and cobalt sulphate. Enough of this solution is poured in to match the colour of the examined water, as seen by looking down through the two short cylinders. Light is transmitted through the tubes by reflection from a plate of white glass fixed at the end of the instrument.

The colour being matched, the depth of the liquid is measured in millimetres and recorded. The 2 feet column of distilled water has approximately a blue tint representing 20 on the older form of tintometer, so that, assuming the water examined to require 20 mm. of bichromate solution to match the colour, it should be entered as blue 20, brown 20. Usually, however, only the number representing the brown is recorded.

The use of the horizontal tubes is troublesome, and we had the apparatus so altered that the tubes could be used in a vertical position. For regular and frequent use, however, we preferred the Lovibond Tintometer. (For information concerning the units employed and the standard scales the Tintometer description booklet² may be consulted.)

¹ W. T. Burgess, F.I.C., Analyst, 1902. Vol. 27, p. 294.

² The Tintometer Ltd., Milford, Salisbury.

The standard form of Tintometer for measuring the colour of water is the B.D.H. pattern, model number 5. This consists of a black bakelite box containing racks fitted with graduated series of coloured glass slides in each of the colours Red, Yellow and Blue.

The sample is placed in an 18-inch cell and viewed in a divided field in the eyepiece, suitable illumination being provided by the white light cabinet shown.

The colour of the water is matched by manipulating the racks so that each glass colour slide in turn, in increasing intensity, passes in front of the second half of the field of view. Two slides of each colour

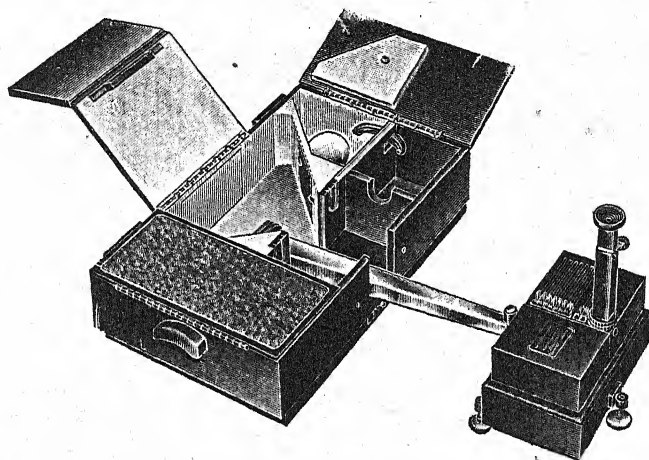


FIG. 14. The B.D.H. Lovibond Tintometer.

can be operative at the same time. When a match is obtained the values of the glasses are recorded from the indicator at the top of each rack.

A turbid water might then read :—

Yellow 7·6, Red 2·4, Blue 1·3.

The colour of good potable waters should be under 0·5 unit yellow. One unit of colour is visible in a large carafe, and a discerning eye can detect it in a tumbler. The following results, obtained when examining daily samples of (a) fairly clear crude river water, and (b) the same water after liming and filtering, will serve to show the use of the Tintometer :—

	Colour of river water (paper-filtered.)					Colour of treated water.
8-1-24	.	.	.	1·6	.	0·5
9-1-24	.	.	.	1·9	.	0·8
10-1-24	.	.	.	1·9	.	0·35
11-1-24	.	.	.	2·1	.	0·3
14-1-24	.	.	.	2·4	.	0·3
18-1-24	.	.	.	2·1	.	0·5
20-1-24	.	.	.	7·3	.	0·65
22-1-24	.	.	.	8·0	.	1·0
26-1-24	.	.	.	2·7	.	0·5

For all practical purposes we find that it is only necessary to register the yellow, but others attempt to obtain greater accuracy by using the blue and red tints also.

The A.P.H.A. standard solution is taken as of a strength of 500 units; therefore, 1 c.c. diluted to 100 c.c. with distilled water (1 per cent.) gives a colour of 5; a 2 per cent. solution, 10, etc.

Burgess's standard is the tint of his solution 1 mm. in depth, and in his apparatus the glass tubes are 2 feet (approximately 600 mm.) in length; therefore, the undiluted solution may be said to have a strength of 600. The units on the two scales would not correspond even had the strong solutions the same tints and the same depth of tint, which is not the case. From the examination of a large number of samples of water we have found that the A.P.H.A. colour figure multiplied by 2.2 corresponds closely with the figure obtained by Burgess's method.

The A.P.H.A. solution is an expensive one to prepare, whereas the Burgess solution is inexpensive and more easily prepared. For this reason we suggest an alteration in the formula for the latter which makes it correspond more closely with that of the A.P.H.A. Then each dilution of Burgess's fluid corresponds to the equal dilution of the A.P.H.A., and the results agree fairly well.

In a long series of parallel determinations, we found that, in raw and filtered river waters containing no undue colour or turbidity, the colour readings obtained by the A.P.H.A. method (Hazen Scale) were approximately 10 times those recorded by the use of the Lovibond Tintometer. When, however, the waters had opalescence and marked colour (150-300, Hazen Scale), this ratio was disturbed and became nearer 15:1.

On the Continent the colour of water is determined in terms of bismarck brown. The unit is 1 c.c. of a 1/40,000 solution of the dye in 1 litre of distilled water. The tint more generally resembles that of river waters than does that of platinum, cobalt, etc., solutions.

In examining a series of moorland river waters, the Tintometer readings averaged 10.5, while the bismarck brown readings averaged 100. The Tintometer readings, if multiplied by 10, closely corresponded, therefore, with the readings on the Continental scale.

Estimations of colour made on the principle of matching with standards suffice for most purposes, and there is not a great deal to choose between the various methods described above. In giving a colour reading for water it is necessary, however, to state the scale on which it is expressed. It is obvious that the results are influenced by the personal factor, the conditions of lighting under which they were obtained, etc., and they are not reliable for comparative purposes.

An apparatus employing a photo-electric cell used for turbidity determinations (*vide* section on Turbidity, p. 215) can also be used for colour determination. Since by this apparatus light is standardised and the personal factor is eliminated, the results are accurate and comparable. The method is simple, and should be used where accuracy

is required, or comparison of one water with another is made. We have adopted this method and standardised it on the A.P.H.A. colour scale, but it can be standardised on any other colour scale, if desired. The water under examination must be bright.

The Odour of Water. When a partially-filled bottle containing water is shaken vigorously, two things should be noted—(a) the frothing produced and (b) the odour, if any.

Water containing much organic matter in solution, when violently agitated with air and then allowed to stand, contains bubbles which do not break instantaneously upon reaching the surface, whereas in water containing very little organic matter the bubbles burst almost instantaneously. The information thus obtained tends to confirm other results, but is rarely recorded. The odour observed is always recorded. If the odour of the cold water is doubtful, about 250 c.c. should be placed in a 500-c.c. stoppered flask, and the flask placed on a water bath until the temperature is about 80° C. The flask is then shaken, the stopper removed and the nose promptly applied to the aperture of the flask. If no odour is now perceptible, the water is regarded as "odourless." Distillation is a good method of detecting faint odours due to volatile substances, for the odour is concentrated in the distillate. Odours not apparent in the cold can be brought out in this way, and the method is of value in judging the efficiency of odour removal from water by such agents as activated carbon. The A.P.H.A. expresses the quality of the odour as "vegetable," "aromatic," "grassy," "fishy," "earthy," "mouldy," "musty," "disagreeable," "peaty," or "sweetish." Occasionally we have had waters with "rotten egg," "tarry," or "petrol" odour, besides those having an odour obviously due to the use of a dirty cork or bottle.

The intensity may be recorded as given in the section on colour. If the odour is suspected to be due to a growth of any kind, the microscope should assist in the detection of its cause. An odour of chlorine or of iodoform should always be recorded when found.

The Taste of Water. When a water has an odour, it almost certainly has a taste. Occasionally, when a water is odourless, there may be a question as to its palatability, for a person accustomed to the use of a soft moorland water may regard it as more palatable than a hard chalk water, and *vice versa*. Some waters may have a flavour which can be surmised from the saline constituents, such as "brackish," "salty," "saline," etc. We cannot define "palatability," but waters which are generally regarded as especially palatable are more or less hard and contain sulphates. Nitrated waters with free carbonic acid are generally very palatable, yet they are usually derived from most unsatisfactory sources.

On the whole, perhaps the water examiner is wise to ignore the question of taste, unless specially requested to report thereon. Since the introduction of chlorine for the destruction of bacteria in water, complaints of taste have not been uncommon, but have rapidly fallen off in number as greater care and skill have been exercised in the use

of this chemical. Some persons are more sensitive than others, and what is called a taste is often nothing more than a sensation of roughness on the palate after the water has been swallowed. In connection with taste, as with odour, the cause may be one requiring microscopical and biological examinations.

Reaction of Water. Litmus solutions will distinguish between neutral, alkaline and acid waters, but a greater degree of accuracy in determining the reaction of waters is desirable. This may be obtained in the great majority of cases by the use of a series of indicators. In the Appendix (*q.v.*) will be found a comprehensive list of these, together with details of preparation of their solutions. The volume of sodium hydroxide given is that theoretically required for the formation of the mono-sodium salt, the indicators themselves being usually only sparingly soluble in water. Some authorities, however, consider this amount of alkali too low for correct working, and prefer to adjust the reaction of the indicator solution to the mid-point of the range of the indicator.

The indicators usually sufficing and which should be available are as follows :—

				pH range.	
No. 1.	Methyl orange	.	.	3.1 to	4.4
„ 2.	Methyl red	.	.	4.2 „	6.3
„ 3.	Bromo-thymol blue	.	.	6.0 „	7.6
„ 4.	Cresol red	.	.	7.2 „	8.8
„ 5.	Phenolphthalein	.	.	8.3 „	10.0
„ 6.	Thymol violet	.	.	9.0 „	13.0
„ 7.	Brilliant cresyl blue	.	.	10.8 „	12.5

No. 1, methyl orange, can be replaced by benzene-azo-*a*-naphthylamine (pH range 3.7 to 5.0), which has a similar, but more distinct, colour change. Table IV. shows the colour changes and corresponding pH values of the above indicator solutions, and will be found to cover the range of practically all waters.

The British Drug Houses Ltd. supply the “B.D.H. Universal Indicator,” which gives readings from 3 to 11, a red colour with pH 3, and the colours then vary from red, orange, yellow, green, and blue to violet at pH 10, in the order of the solar spectrum.

It is very useful for giving an indication of the hydrogen-ion concentration, but should always be confirmed by the use of individual indicators in the following manner :—

A uniform series of test tubes, each with a graduation mark at 10 c.c., is desirable, and the indicators should be of such strength that 0.4 c.c. suffices in all cases. The exact measurement of the water and of the indicator used is most important.

Commence by adding bromo-thymol blue. If, upon mixing, the colour is bluish-green, the water is neutral. If green or yellow, the water is more or less acid. To another portion methyl red should be added; if this gives a red colour, another test must be made with methyl orange.

TABLE IV.

Indicator.	pH Range	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13
7. Brilliant Cresyl Blue	10.8—11.6																B	BG	GBr			
6. Thymol Violet	9.0—13.0													Y	YG	G	GB	B		I		V
5. Phenolphthalein	8.3—10.0											C	FR	R	M							
4. Cresol Red	7.2—8.8									Y	O	R	MR	M								
3. Bromo-thymol Blue	6.0—7.6							Y	YG	GB	B											
2. Methyl Red	4.2—6.3				R	OR	O	Y														
1. Methyl Orange	2.9—4.6	R	OR	O	OY																	

pH Value

0.01N HCl
 0.001N "
 0.0001N "
 N Acetic Acid
 0.1N "
 0.01N "
 0.001N "

Pure Water, true neutrality pH value 7.0
 Water + 1 pt./100.000 Ca(OH)₂ 11.0

B Blue
 Br Brown
 G Green
 Y Yellow
 I Indigo
 C Colourless
 V Violet
 O Orange
 R Red
 M Magenta
 F Faint

If, on the other hand, bromo-thymol blue gives a blue colour, the cresol red and other indicators must be added in proper sequence until the tint corresponds with that given by the indicator as shown in Table IV.

No. 7, brilliant cresyl blue, is only useful when water is being treated with lime. It is probably the best indicator for revealing the presence of a trace of hydrate in the presence of carbonates, when water is being softened or treated with excess lime.

The CaCO_3 which remains in solution when water is softened with lime has no effect on the brilliant cresyl blue; hence, in a water being softened, the first trace of green with this indicator signifies the presence of a trace of free lime.

When the pH value of a water is below 7, this is usually due to the presence of free carbonic acid. A water saturated with CO_2 has a pH of 4.5 to 5, and has a very faint action even on methyl orange.

When the pH is 5 or below, it may be due to the presence of an inorganic or organic acid. If due to the former, a drop or two of a

dilute solution of sodium acetate raises the pH value; whilst if the acidity is due to CO_2 or a weak vegetable acid, such as that in many moorland waters, the colour is not affected.

Messrs. Allen & Hanburys and the British Drug Houses Ltd. supply mixed indicators which are very useful for field work, and the B.D.H. comparator case is a convenient outfit. As this contains sealed buffer tubes of different pH values,

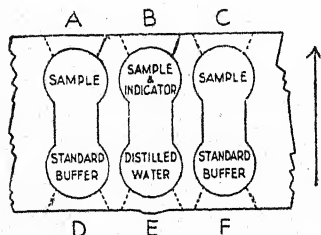


FIG. 15.

comparisons are easily effected. For the determination of the hydrogen-ion concentration of a colourless water, 10 c.c. are placed in one of the tubes, the proper quantity of the indicator added, and a direct comparison made with the buffer solutions. If the water is coloured or slightly turbid, three tubes are filled with the water and placed in the appropriate spaces of the comparator (marked A.B.C., Fig. 15). The indicator is added to the tube B, and in front of it, in the position E, is placed a tube of distilled water. The buffers are placed in D and F and the colours compared by viewing in the direction of the arrow through the three pairs of tubes.

Another convenient form of apparatus now much used for pH determinations in field-work, waterworks, etc., is the Hellige comparator, which also depends on matching the colours of indicator solutions. It has the advantages of being compact and the matching standards are in the form of coloured glasses or discs which do not fade. In all these pH determinations the liability of interference should be kept in mind. Acid-fumes, lime dust, etc., in the atmosphere, dirty glassware, and the contact of the sample with the fingers are all likely to vitiate the results. Interference will also be caused by the presence of appreciable free chlorine in the water, such as 2.0, or more, parts per million, but such concentrations seldom occur in potable waters.

It is very seldom that precise pH figures are required, or that sufficiently reliable results are not obtained by the use of indicators as described above. For more precise determinations an electrical cell with standard electrodes is used. The electro-motive force of this cell, with the water under test as the "bridge" between the electrodes, is estimated. An apparatus of this type, the "Cambridge pH Meter,"¹ employs quinhydrone glass and calomel electrodes, and the potentiometric system has a Weston reference cell in conjunction with a thermionic valve. This arrangement overcomes certain practical difficulties attendant on determinations of hydrogen ion concentration by this method, and the apparatus can be operated without great technical skill. Calibration of the instrument is made with buffer solutions, and indicator solutions are not used.

The measurement of pH by this apparatus is not affected by the presence of suspended matter or colour in the water under examination.

The principles used in the Cambridge pH meter are also employed in the continuous measurement and recording of pH value in waterworks plant operation and control.² The standard electrodes and the reference cell of such apparatus come into contact with the water being tested and form a primary unit. This primary unit is designed either for insertion into channels of flowing water or to take a bye-pass flow bled from a main. The unit thus contacting the water is connected to the recording component of the apparatus. The latter houses the potentiometric system which measures the pH , and also the electrically operated mechanism which records and charts the measurements. In operation, the galvanometer needle in the potentiometric system takes a position dependent on the pH value of the water. The recording mechanism transfers and marks, from the position of the needle, the pH value on to a chart, and it repeats this cycle of working every two seconds.

These instruments for continuous recording of pH are invaluable at waterworks employing such processes as alkalisation by lime for the prevention of corrosive action, lime softening, or sterilisation of water by excess lime.

Temperature. Occasionally it is desirable to record the temperature of a water as it rises from its source and to compare it with the air temperature at the same time, or with the temperature of other waters. The temperatures of many samples taken directly from deep wells in Essex were recorded in the hope that their study would give information of value. The results, at present, seem inexplicable, deep wells not far apart yielding waters differing considerably in temperature. We have observed, however, that in the waters with the higher temperature the multiplication of bacteria is more rapid than in the waters with a lower temperature. Therefore, when waters with a temperature of about $15^{\circ}C$. are collected for bacteriological examination, they should be cooled down as quickly as possible.

Generally speaking, the higher the temperature of a spring water

¹ Manufactured by the Cambridge Scientific Instrument Co.

² The Kent Multelec pH Recorder, manufactured by Messrs. George Kent Ltd., Luton.

the deeper the source from which it arises. Water issuing from fissures in chalk or other rocks may show variations in temperature, and on at least one occasion this variation in temperature put us

on the track of a previously unsuspected source of pollution. An accurately graduated thermometer with the bulb near the bottom of a metallic cup is the most generally useful form of instrument, but in some cases maximum and minimum registering thermometers are necessary for obtaining accurate results. The air temperature at the time of taking the water temperature should always be recorded.

The apparatus illustrated in Fig. 16 has proved most useful in taking the temperature of waters in deep wells. It consists of a weighted thermos flask containing the thermometer, and inlet and outlet tubes passing through the rubber stopper. It is lowered quickly to the desired depth, allowed to stand until air bubbles cease to rise and then withdrawn, when the temperature can be read before the bulb is removed.

The following are the temperatures of a number of deep well waters taken in various

parts of Essex ("Water Supply of Essex," Whitaker and Thresh):—

TABLE V

Depth below O.D.	Temperature in Centigrade degrees.	Depth below O.D.	Temperature in Centigrade degrees.
486	12.7	275	15.6
489	13.0	326	15.9
313	13.6	792	16.1
826	14.2	463	16.2
264	14.5	590	16.2
220	14.6	365	16.2
378	14.6	791	16.5
278	14.7	580	16.7
302	14.7	710	16.8
775	14.8	427	17.0
612	15.0	752	17.4
286	15.0	315	17.4
297	15.2	775	17.6
671	15.2	686	17.8

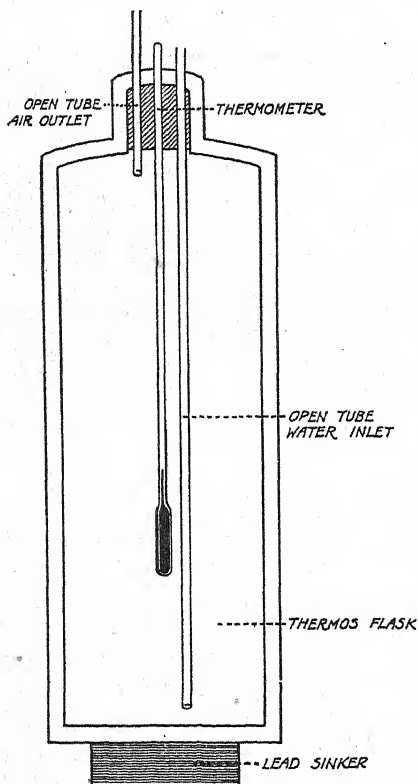


Fig. 16.

Unfortunately, all these temperatures were taken before the thermos flask arrangement had been adopted, and in all cases the temperature recorded is that of the water as it flowed from the rising main into the tank at ground level.

In the case referred to in which the temperature results led to the discovering of an unsuspected source of pollution, the temperature of the water at the inlet to the service reservoirs was found to be several degrees higher than the water in the well. Inquiry showed that a portion of the water was diverted from the rising main below the engine house floor, passed through a condensing arrangement, and then back into the rising main at a higher level. A sample of water taken from the well contained no *Bact. coli*, yet as the water left the rising main this organism could be found, and it was also found more abundantly in a sample of water taken from the condenser.

This is not the only occasion on which we have found condenser water causing pollution in a public supply. In another case we discovered water from a condenser leaking into a well through the ground under the engine house. The water trickling in was found to contain *Bact. coli*, and the slimy growth below was loaded with coliform organisms and fully accounted for their presence in small numbers in the water from the well.

In Australia, where borings have been made to a depth of 7,000 feet, the temperature of the water is said to exceed 100° C.

Turbidity and Amount of Sedimentary Matter. Very few waters are absolutely free from suspended matter, but this may vary from a few barely visible specks to an appreciable deposit or marked turbidity. The coarse suspended matter, which settles rapidly, need never be run upon a filter since it can easily be removed by passing the water through a small sedimentation tank or collecting reservoir, but the finer particles can only be removed by filtration, and in some cases only when a coagulant, such as aluminium sulphate, has been added to the water prior to filtration.

The finest suspended matter is in the colloidal condition. Particles above a certain size are said to belong to the "coarsely-dispersed" system, whilst smaller particles belong to the "colloid" system. In a true solution the solid matter belongs to the "molecularly-dispersed" system. The following quotation from "Theoretical and Applied Colloid Chemistry," by Ostwald and Fischer, will explain these different systems:—

"A practical division between coarsely-dispersed and colloid systems can be made, for instance, microscopically. It follows, from the theory of microscopic vision, that we cannot see individual particles of a diameter of less than half a wavelength of light. By employing micro-photographic methods which enable us to work with the short waves of ultra-violet light, we obtain as the limits of microscopic vision a value of about one ten-thousandth of a millimetre or 0.1 μ . This value is used—let it be noted, altogether arbitrarily—as making the transition from coarse to colloid dispersions. Other methods of

investigation, such as filtration, yield similar values. The pores of the best grades of hard filter papers (No. 602 of Schleicher and Schull) are about $1\ \mu$ in diameter; those of clay and porcelain filters about $0.2\ \mu$ to $0.4\ \mu$. These values, therefore, approximate those obtained by microscopic means. It is characteristic of typical colloids that they pass through these filters, while coarse dispersions do not."

Dispersed systems lying between these middle limits pass through paper filters and through a Berkefeld filter, but are stopped by a Pasteur filter, and are typically colloid. The authors above quoted, however, add: "Let us again emphasise that we deal with purely arbitrary divisions and that we are familiar with transition systems

of every degree of dispersity, not only between coarse dispersions and 'colloids,' but between these and molecularly-dispersed systems. Colloid matter occurs in practically all river waters, especially after heavy rainfalls, and is chiefly due to clay (a typical colloid), but it is associated with other particulate matters which, though not sufficiently small to belong to the colloid system, yet approach those dimensions, and consequently settle very slowly."

To estimate the amount of the finely-dispersed matter is difficult, but a very approximate determination may be made in the following ways, using a dispersion of fullers earth (made as described in formula No. 37 in the Appendix) which contains 1 gramme of the clay in a litre of water. It may be remarked that if a sample of the water in a clear, colourless glass bottle can be described as

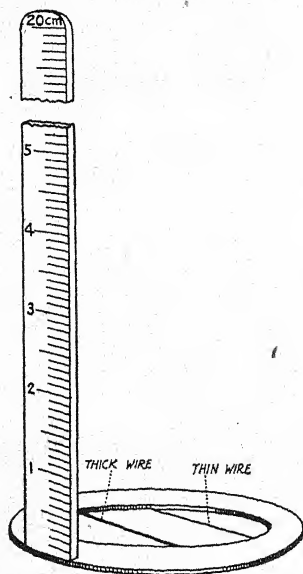


FIG. 17.

"brilliant," "bright," "clear," or "merely dull," it should be described as such, and no further examination is usually necessary.

If the turbidity is evident, determine it in the following way: Fill a litre bottle with the water to be examined and compare with a similar bottle of distilled water to which has been added 1, 2 or more cubic centimetres of the fullers earth suspension, the comparison being made by transmitted light. Results are expressed in terms of parts per million, Silica Scale. Thus, if 1 c.c. of the fullers earth suspension were used, this corresponds to 1 mg. of the clay, and if this were diluted into 1 litre of distilled water, the turbidity would be 1 part per million, Silica Scale.

For turbidity of 50 and upwards the following method is preferable:—

Requisites. A colourless glass cylinder about 15 cm. long and not more than 5 cm. in diameter.

A rod graduated in centimetres or millimetres attached to a circular frame carrying two platinum wires, one 1 mm. in diameter, and the other 1.5 mm. (*vide* Fig. 17).

Pour into the tube the water to be examined, place in a good light, but not in direct sunlight, insert the wires and lower until the 1-mm. wire is no longer visible with the eye vertically over the needles; read off the depth of the needle from the surface of the water.

Instead of the cylinder, the 1-foot horizontal trough of the original Lovibond Tintometer may be used. The trough is covered with a well-fitting lid having a slot down the centre. In this slot is a platinum needle affixed to a plate which can be pushed backwards and forwards. The needle is changed in position until, upon looking through the eyepiece, it can be just faintly discerned. A scale at the side of the slot gives the distance of the needle from the front glass of the trough, and a reference to the appended table, taken from a specially prepared chart, gives the degree of turbidity.¹ The needle reading in centimetres might be called degree of clarity (*vide* Fig. 18).

TABLE VI

Reading of needle.	Turbidity.	Reading of needle.	Turbidity.
2 cm.	100	15 cm.	6.5
3 "	55	16 "	6
4 "	36	17 "	5.5
5 "	24	19 "	5
6 "	19	20.5 "	4.5
7 "	15	23 "	4
8 "	13	26 "	3.5
9 "	11	30 "	3
10 "	10	35 "	2.5
12 "	8	43 "	2
13 "	7.5	55 "	1.5
14 "	7	80 "	1

With readings above 30 cm. the determination is made by the bottle method first described, or by using a trough 2 feet in length.

In the United States the Geological Survey recommends the use of a specially graduated rod, with a mm. platinum needle at the end. The point at which the wire becomes invisible then gives the reading of the turbidity expressed in parts per million of fullers earth, *i.e.*, Silica Scale.

In ordinary potable waters the turbidity is too slight to be measured in the above way, and Mr. C. Anthony devised an instrument depending upon the action of polarised light.

The Anthony turbidimeter consists of two parallel tubes, one of which of standard length, viz., 50 cm., closed at the ends by plates of glass, contains the water to be examined, and the other a Nicol prism.

The ends of these tubes are covered with caps containing ground-

¹ These figures multiplied by 10 give the results in parts per million, silica scale.

glass screens of the same density. These two sources of light are examined through the eyepiece containing another Nicol prism, and,

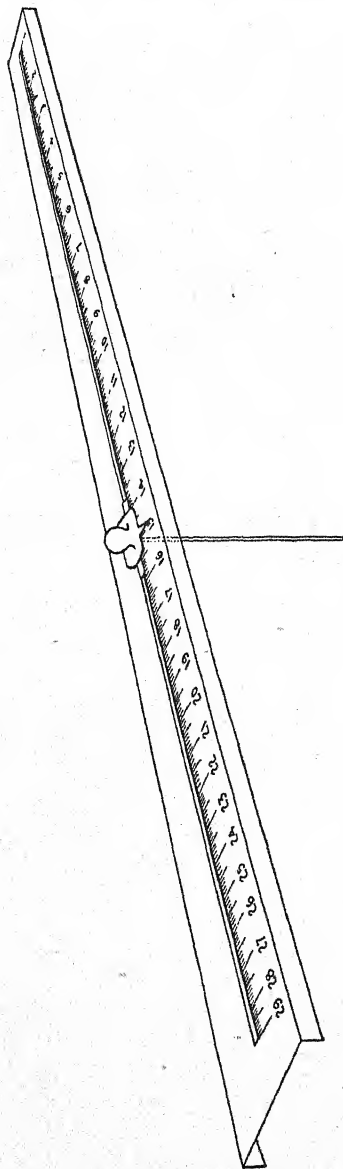


FIG. 18.

by employing a rectangular prism between the eyepiece and the two tubes, the field of view is seen nearly dechromatised, one half being illuminated from light coming through the tube containing the water under examination, whilst the other half receives light from the tube containing the Nicol prism. By rotating the eyepiece, the illumination of the latter half of the field, seeing that the light has already passed through a Nicol prism, can be varied until it matches the half receiving light through the standard thickness of water under examination. To the eyepiece a pointer is attached which rotates through 90 degrees and indicates the amount of turbidity of the water to a rational scale, in which 0 represents perfect transparency, and 1 total obscuration. When water of greater turbidity is to be examined, the tubes can be unscrewed and the lengths reduced to 25 or $12\frac{1}{2}$ cm., when the results read must be multiplied by 2 or 4 to bring them to the standard length of 50 cm.

If the turbidity of the water is such that even with the $12\frac{1}{2}$ -cm. tube length it is too opaque to permit of an accurate determination, recourse must be had to dilution with an equal or double volume of distilled water, when the results must be still further multiplied by 2 or 3 to bring them into due relation with the standard tube length of 50 cm.

The instrument can be used with practically any illumination, and is

packed in a mahogany case which also serves as a stand.

Another very useful instrument, especially for observations on fairly clear and filtered waters, is the Paterson Turbidity Meter.¹

¹ Supplied by The Paterson Engineering Co. Ltd., Windsor House, Kingsway, London, W.C.2.

This is a compact optical instrument consisting of a rectangular water reservoir with a movable cover. On the longer sides are two mirrors facing each other. In each mirror an aperture is formed, one of these permitting the passage of a light ray from a lamp of standard strength, whilst the other allows the interior of the reservoir to be viewed. On filling the interior with water and switching on the attached electric light, multiple reflections are obtained of the original light-spot, these reflections being visible as a row of light spots on the mirror face opposite to the inspection aperture, the number of such spots being a measure of the turbidity.

To obtain a reading it is only necessary to move a slider mounted on the cover until the slider touches the last visible spot. A pointer fitted to this slider gives a direct reading on a scale in degrees of turbidity (in terms of parts per million, Silica Scale). The instrument is very sensitive and readings as low as 0.2 degrees can be obtained.

A turbidity of 5 parts per million is given by a water with a faint and barely perceptible opalescence.

It is now customary to express the degree of turbidity in terms of parts per million, Silica Scale. Apparently the fullers earth of commerce is the same in this country as in the United States, since the standard solutions we have prepared correspond exactly with the A.P.H.A. standard. The most precise and scientific instrument for turbidity measurement is, in our experience, the B.T.L. Photoelectric Turbidimeter and Colorimeter¹ (Fig. 19), and we now employ this apparatus in preference to all others. This instrument, designed in

collaboration with the Metropolitan Water Board's Laboratory, London, uses a photoelectric cell to measure light transmitted through water. Great sensitivity is obtained, and errors due to the personal element are eliminated. The apparatus is simple, compact, and easy to manipulate. Its component parts include the following:—Vulcanite tubes with bases of white glass, made in two sizes, which carry water to a depth of 15 cm., and 45 cm., and hold 275 c.c. and 800 c.c. respectively. A small electric bulb, illuminated by a 6-volt accumulator, is contained in a lamp fitted with a lens and an iris diaphragm. The lamp fits into the head of the tubes, and a parallel beam of light is focussed through

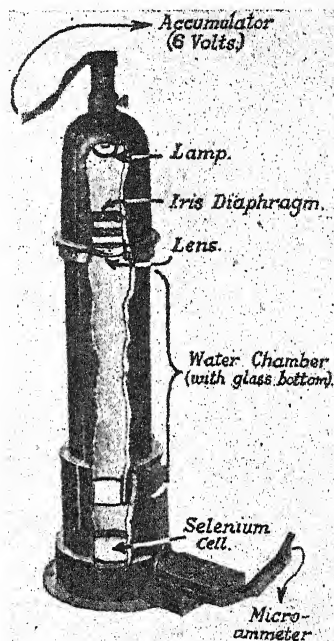


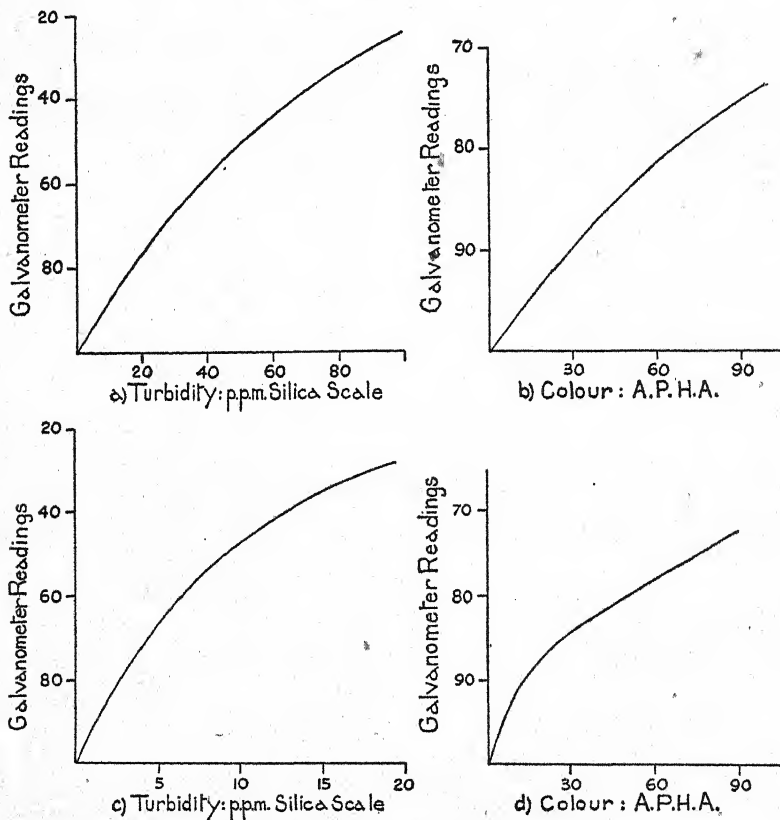
FIG. 19.

¹ Made by Messrs. Baird and Tatlock Ltd., Hatton Garden, London.

the water, the adjustment of the quantity of light being made with the diaphragm. The lamp and tube are housed over the photocell, and the light received by the cell is measured by a microammeter reading up to 120 microamperes.

To standardise the instrument a tube is filled with distilled water, and the illumination from the lamp (having first been focussed into a parallel beam) is adjusted so that the galvanometer registers 100 microamperes. By substituting in the tube various standard sus-

TABLE VII



pensions of fullers earth (or standard colour solutions) curves are plotted as shown in Table VII. Curves (a) and (b) show the standardisation of the smaller tube, and (c) and (d) that of the larger tube.

Readings on this instrument with natural waters are influenced by both the colour and the turbidity, and for this reason we suggest that two terms be used. Having adjusted the illumination, *i.e.*, the galvanometer reads 100 microamperes when the tube is filled with distilled water, a coloured and turbid water when substituted gives a certain reading. This reading translated from the turbidity curves (a) or (c),

gives a figure which we call "total opacity." If the water is now filtered and an estimation of colour made, a galvanometer reading corresponding to this colour is taken from curves (b) or (d). This reading has a certain turbidity value which can be read from curves (a) or (c), and it is this value which represents that part of the "total opacity" due to colour. When this equivalent amount is deducted, the remaining figure represents the turbidity.

Since the curve of the range over which readings are taken (dilutions are made outside this range) is almost a straight line, and since the colour deduction is in most cases comparatively small, this method of allowing for the colour of a turbid water is justified.

Colour, after filtration of the water, is estimated by visual matching against a standard.

Owing to the fact that turbid waters seldom filter bright, a large error occurs if the instrument is used to determine colour in such cases, which error is caused by the residual suspended matter. As stated in the section dealing with colour, the use of the instrument for colour determination requires a bright water.

The use of the instrument is illustrated by the following example: A turbid discoloured water when placed in the 15 cm. tube gave a galvanometer reading of 45 microamperes, *i.e.*, the total opacity from curve (a) was 59 parts per million, Silica Scale. The water, having been filtered, gave a colour figure of 30 A.P.H.A. This colour figure, from curve (b) corresponds with a galvanometer reading of 90, and, reverting to curve (a), 90 microamperes is equivalent to a turbidity of 8. Thus, the total opacity of the water is 59, and its turbidity is 51.

Resistance to Filtration. In Sir A. Houston's 17th Annual Report to the Metropolitan Water Board is a section headed "Resistance to Filtration and Microscopical Appearances of Pre-filtration Waters." He described the methods used in his laboratory as follows:—

"All the pre-filtration waters, and the raw waters as well for comparative purposes, are tested for 'resistance to filtration,' by which is meant the degree to which the suspended matters (living and dead) in a water interfere with its filtration by blocking the filtering material. Although the sand filter is the real test in this connection, quite useful results may be obtained in the laboratory in the following way: A piece of linen of superfine quality (ninety-six meshes to the linear inch) is folded four times, moistened with water, and tied round the end of a glass tube ($\frac{1}{4}$ inch diameter) by means of a rubber band. The tube is passed through a rubber bung which is fitted into a filtering flask connected with a filter pump. The other projecting end of the glass tube has a piece of rubber tubing attached to it, and into this is inserted the end of a pipette containing 100 c.c. of the sample of water to be examined. The water passes through the linen into the flask, and practically all the suspended matter is retained on the inside of the linen. The rubber bung and glass tube are then detached and fitted on to the additional piece of apparatus.

"This is merely a convenient arrangement for supplying tap water

under a constant head (about 5 feet). The water is filtered through the linen, with its skin of suspended matter derived from 100 c.c. of the original water, for the space of one minute, and the filtrate is then measured."

In a diagram at the end of his report, headed "Resistance to Filtration," the figures really refer to the "filtrability," since the greater the resistance to filtration, the smaller the amount of water which passes through.

The method we have employed is simpler, and is more generally

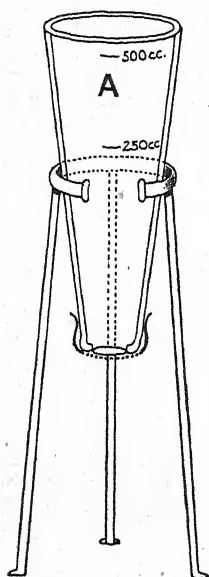


FIG. 20.

useful in the laboratory since it also serves for collecting the deposit for further examination. The apparatus consists of a conical tube A (Fig. 20) with the narrow extremity ground flat. The diameter of this narrow end is about 2.5 cm., and of the larger end about 7 cm. On the narrow end is placed a rubber ring, and over this a disc of stout filter paper of the diameter of the neck. The whole is secured in position by a piece of netting tied round the flange on the neck. An indiarubber cap can be slipped on the whole. A litre flask with a long, narrow neck is filled to the graduation mark with distilled water, and the conical tube is also filled with the water to a mark indicating that it holds 500 c.c. The thumb being placed over the mouth of the litre flask, the latter is inserted into the water in the tube and supported by a clamp at such a height that the mouth is exactly on a level with the 500 c.c. mark. The rubber cap is then slipped off and the moment noted when the first bubble of air enters the litre flask. When the last drop of water has left the flask, the time is again noted, and the

difference gives the time required for 1 litre of the distilled water to pass through the filter under constant pressure. This is taken as unity. A fresh filter paper is affixed, and the experiment repeated at the same temperature with the water to be examined. The resistance to filtration is the ratio of the time taken by the water to that taken by the distilled water.

A fresh filter paper must be used for each test, and its uniformity should have been ascertained by experiment. White blotting paper bearing the watermark "Ford 428 Mill" seems to be fairly uniform in texture, and reliable. The following are the results obtained in examining a few samples of water :—

	Time required to filter 1 litre.
1. Distilled water	4 min. 15 sec.
2. A bright well water	7 " 0 "
3. An unfiltered moorland water	12 " 55 "
4. A filtered river water	6 " 34 "
5. An unfiltered river water.	Over 24 hours.

Taking the distilled water "resistance to filtration" as the standard, we have—

			Repeated.
Distilled water	1.0	...	1.0
Well water	1.6	...	1.42
Unfiltered moorland water . .	3.0	...	—
Filtered river water	1.5	...	—
Unfiltered river water	Over 350	...	Over 350

corresponding to the resistance to filtration of the respective waters. In the above cases the moorland water was more turbid than the unfiltered river water, and apparently the filtrability or the resistance to filtration does not depend entirely upon the degree of turbidity. The subject is of importance in connection with rapid sand filtration, since we have found that a turbid river water could be passed through such a filter for a longer period than a less turbid water without cleansing of the filter. Observations on the turbidity showed that the filtrability was affected by something besides the visible suspended matter, and this is doubtless due to substances in a colloid condition. Records were therefore made of the resistance to filtration, using the conical 500-c.c. vessel only and recording the time required for 250 c.c. to pass through the filter disc. The results were astonishing. For example, taking one week during a rainy season, the records were :—

Time required to pass 250 c.c.	Water River No. 1.	Water River No. 2.
1st day	2 min. 0 sec.	5 min. 5 sec.
2nd „	Over 2 hours.	Over 2 hours.
3rd „	„	„
4th „	„	„
5th „	6 min. 21 sec.	22 min. 23 sec.
6th „	63 „ 10 „	—
7th „	Over 2 hours.	Over 2 hours.

When water on the sixth day had been treated with lime and allowed to settle, the filtration period was reduced to seven minutes five seconds, and after the subsequent addition of 1 gr. per gallon of aluminium sulphate it fell to three minutes fifty-two seconds. With 2 gr. of aluminium sulphate the results were not so good, the time required being six minutes twenty-seven seconds.

With waters which failed to pass 250 c.c. in two hours neither lime nor aluminium sulphate caused any marked improvement in four hours.

CHAPTER XVII

ESTIMATION AND EXAMINATION OF SUSPENDED MATTER

If it is desired to estimate the weight of the matter in suspension, the best way to do so is to pass from 100 c.c. to 1 litre of the water through a tared Gooch crucible fitted with a thin layer of asbestos. After sufficient water has been passed, the crucible and its contents can be again dried and weighed. The temperature at which this is done should be recorded, and that most suitable is 120° C. Some information with regard to the organic matter present is obtained by ignition and subsequent re-weighing.

The following method was adopted by Professor Boyce and others in their examination of the River Severn waters for the Royal Commission on Sewage Disposal. It requires the use of a large centrifuge. Six hundred cubic centimetres of the water are centrifugalised, the clear liquid pipetted or siphoned off, and the remainder transferred to a small specially constructed tube, the bottom of which is drawn out like a thermometer tube and graduated in 0.01 c.c. "The glass is filled and centrifugalised for two and a half minutes in a hand centrifuge making about 2,000 revolutions per minute; the result is that the deposit is forced into the graduated stem and the amount can be easily read off."

The brightest water, even distilled water, leaves a few specks upon the paper when 1½ litres have been passed through the apparatus used for determining the resistance to filtration and described in Chapter XVI. Usually the stain is reddish, due to a trace of ferric carbonate or hydroxide. The paper, after use in the apparatus, can be examined under the microscope employing a low-power objective, or the deposit may be washed off into a watch glass for further examination. If the filter paper used has been previously tared, the weight of the deposit can be ascertained.

To obtain all the information necessary, it usually suffices to fill a conical test glass with the water and set it aside for twenty-four hours, when the larger organisms and other matters in suspension will settle upon the sides and bottom of the glass. By carefully siphoning off the supernatant clear liquid, the suspended matter is concentrated into a very small volume of water, and droplets can be removed for examination, using the low-power objective of the microscope. For this purpose hollow-ground slides are very useful. Macroscopic particles can be separated for examination by removing with a pipette. When it is desired to preserve such deposits for future

examination, they can be preserved in a solution of cupric chloride, etc., in camphor water (*vide* formula in Appendix).

To collect the organisms from water passing through mains, a small bag of fine linen may be tied over the mouth of a tap which is then left running for a period. When the bag is removed, it is turned inside out and gently immersed in a small quantity of water to remove all the organisms, or a piece of fine linen may be tied over the small end of a funnel and a quantity of water passed through. The linen is then removed, and the deposit can be detached and placed upon a slide for examination.

With the aid of a wash bottle containing filtered water, the deposit on the filter paper may be washed into a small tube drawn out to a point at the end, and the tube then centrifuged. The deposit is thus obtained at the point of the tube, and an idea can be formed of its quantity. It can then be transferred to a slide for examination under the microscope.

For collecting the deposit formed on filter paper, Mr. Dibdin suggested the following method which admits of the amount of sediment being expressed numerically. The end of a piece of combustion tubing is drawn out until the capillary portion has an internal diameter of 2 mm. The end of this is plugged with a paste of clay and kieselguhr and heated to redness to "set" the mixture. The filter deposit is washed into this tube and filtered out by the kieselguhr plug, the process being accelerated by the use of the filter pump. When only a drop of the water remains in the micro-filter, the length of the deposit can be measured. The end of the capillary tube can be cut off and the deposit blown out upon a slide for examination.

With very clear waters a litre or more may be required to furnish any visible deposit, but 250 c.c. or less suffice with most waters submitted to examination.

There is a difficulty sometimes in removing the deposited matter without damaging some of the organisms to such an extent as to render their recognition impossible. This is obviated by the quantitative and qualitative method known as the Sedgwick-Rafter method. The following description is taken from Rafter's book "The Microscopical Examination of Potable Water."

"The bottom of a funnel is plugged with wire cloth, and upon this is placed about $\frac{1}{2}$ inch of clean coarse sand. This is lightly pressed with a glass rod, and from 20 to 40 c.c. of freshly-filtered water allowed to run through to ensure the settling of the sand. The amount of water to be filtered is gauged by the number of organisms which it contains, as ascertained by a preliminary inspection. Generally, however, as large a quantity should be used as can be conveniently filtered without clogging the sand so much as to render the completion of the process too prolonged. For all ordinary purposes, 500 c.c. suffice. The first 100 or 150 c.c. passed through are returned to the funnel. After all the water has passed through, the wire cloth is removed and the sand and contained organisms washed with 5 c.c. of freshly-filtered

water, run from a 5-c.c. pipette into a 5 or 6-inch test tube. The test tube is slightly shaken to wash all the organisms clear from the sand, the latter, from its greater specific gravity, sinking quickly to the bottom, leaving the organisms distributed through the water. At the instant of the completion of the settling of the sand the supernatant water is turned into another smaller test tube, leaving the clean sand at the bottom of the first tube. The organisms from 500 c.c. of water are now concentrated in 5 c.c. After slight stirring to secure uniform distribution, 1 c.c. is transferred by means of a pipette to a specially prepared cell of 50×20 mm. area and of exactly 1 mm. in depth. Such a cell, of course, just holds 1,000 c.mm., or 1 c.c. The top of the cell (preferably the sides should be constructed of metal) is ground perfectly smooth, and a cover glass, thoroughly cleaned and moistened, is placed over it by sliding gently from one end. With a little practice, this can be done without enclosing any air bubbles or losing a drop of the liquid."

For the purpose of enumeration, an eyepiece micrometer is required, so ruled as to cover, with a given objective and fixed tube length, a square millimetre on the stage. The mechanical stage recommended has a precise millimetre movement, so that the position of the squares counted is definitely known. This movement is insisted upon as an integral part of the method. Rafter recommends that about fifty squares should be counted. The working objective for these counts may be either a $\frac{2}{3}$ or a $\frac{1}{2}$ inch. In certain cases a high power may be required for identification purposes.

The amorphous organic matter is estimated "mentally," a unit of area being 20 square microns.

The subjoined table shows how the results are tabulated :—

NUMBER OF ORGANISMS PER C.C.

Source of sample	Spring	Lake waters of medium quality		
		1	2	3
Sponge spicules	0	0	1	1
Rhizopods	1	0	1	0
Infusoria	0	21	50	16
Rotifera	0	3	6	1
Crustacea	0	0	1	0
Total animals	1	24	59	18
Desmidiæ	0	3	4	5
Diatomaceæ	8	19	45	50
Zoospores	26	244	88	2400
Chlorophyceæ	0	55	13	1
Cyanophyceæ	0	157	110	0
Fungi	0	0	0	0
Total plants	34	478	260	2456
Amorphous matter	165	238	230	45

Passing next to the microscopical appearances, the following photographic method was used by Sir A. Houston to give both a qualitative and quantitative picture of its nature :—

Twenty cubic centimetres of the water are placed in a glass tube and centrifuged, the result being that all matters in suspension are driven to the bottom of the tube. The contents are then carefully poured off to a little above the 0.2 c.c. top mark on the narrow portion of the tube. A pipette is then used to remove the water to exactly the level of the 0.2 c.c. top mark, care being taken not to disturb the sediment. The water is expelled from the pipette which is then used to mix the deposit thoroughly with the water remaining in the tube. Between the two marks is exactly 0.1 c.c., and this amount, or one-half of the whole of the suspended matter in 20 c.c. of water, is transferred by a pipette to a small cell cemented on to a glass slide. A trace of formalin is added to prevent the movement of any motile organisms that may be present, and now we have 0.1 c.c. of water lying in the cell ready to be photographed.

The glass slide is next centred so that the centre of the cell lies exactly below the centre of the lens. A magnification of 50 diameters is employed, as this in most cases is quite large enough for diagnostic purposes, and it gives a reasonably flat and relatively large field. Of course, the whole of the 0.1 c.c. is not photographed, but it has been found experimentally that about one-twentieth part appears in the picture, which corresponds to the suspended matter in $\frac{1}{2}$ c.c. of the original water.

An expert biologist who has made a special study of this subject may venture to name most of the organisms found in waters, but it is impossible even for an expert to recognise all the forms. There is no doubt that some fresh-water algæ, for example, exhibit many different forms during their life histories, and some now bearing different names are really the same organism at different stages of its existence.

Those who wish to make a detailed study of these low forms of vegetable and animal life must consult special treatises on the subject, such as :—

Cooke's "British Freshwater Algæ, exclusive of the Desmidiæ and Diatomaceæ."

Cooke's "British Desmids."

Smith's "Synopsis of the British Diatomaceæ."

De Barry's "Comparative Morphology and Biology of the Fungi Mycetozoa and Bacteria."

Baird's "Natural History of the British Entomostraca."

Hudson and Gosse's "The Rotifera."

Allman's "Freshwater Polyzoa."

Kent's "Manual of the Infusoria."

Whipple's "The Microscopy of Drinking Water."

The best single works in English covering the whole ground are probably "Fresh Water Biology," by Ward and Whipple, and

"The Microscopy of Drinking Water," by Whipple, both published in London by Messrs. Chapman and Hall, Ltd.

The objects seen under the microscope can be divided into five groups :—

1. Mineral matter.
2. Dead vegetable matter.
3. Dead animal matter.
4. Living vegetable organisms.
5. Living animal organisms.

The mineral matter, as a rule, admits of easy identification.

If the presence of chalk is suspected, a little dilute hydrochloric acid may be run under the cover slip, when the particles of chalk will be seen to dissolve giving off bubbles of gas. If oxide of iron is present, a droplet of solution of potassium ferrocyanide may be passed under the cover slip after the acid, when the presence of iron will be revealed by the production of a blue colour. Particles of clay and sand will be unaffected by these tests.

Dead vegetable matter is often difficult to recognise, but usually some cell or fibre will have escaped complete disintegration and thus aid in its identification. Dead animal matter is, as a rule, more readily recognised, as destruction by maceration is rarely so complete as to obscure the origin of the *débris*.

The differentiation of animals from plants is frequently exceedingly difficult, if not impossible, in the lower forms of life. The presence or absence of organs of locomotion is not always reliable for the differentiation, as many algæ in certain stages of their existence possess flagella, whilst other organisms, which on physiological grounds must be classed as animals, are either motionless or require prolonged observation to detect their motility.

Search should be made for animal and vegetable growths the presence of which has special significance. The more important of these are referred to in Chaps X. and XI., or are illustrated on one or more of the plates in the Appendix.

A careful study of the illustrations of deposits found in waters from various sources will, when taken in connection with the descriptions of the sources from which they were derived, suffice for most practical purposes to enable an observer to draw reliable conclusions as to the source of the suspended matter found in a water. This is the most which can be attempted by anyone who has not made a prolonged and systematic study of the lower forms of animal and vegetable life.

CHAPTER XVIII

CHEMICAL ANALYSIS

Determination of the Total Solids

THE estimation of the total solids is sometimes regarded as one of the simplest operations in water analysis. This is not the case, for the determination is one requiring considerable skill and experience.

For the evaporation of the water a platinum dish, capable of holding about 60 to 70 c.c. and weighing about 35 grammes, is most suitable. After being polished with a little sand-soap and thoroughly cleansed with distilled water, the dish is placed on the water-bath for a few minutes, care being taken that nothing splashes on to the bottom of the dish. A flanged glass ring fitted to the water-bath and projecting $\frac{1}{2}$ an inch into it prevents particles of mineral silt, oxides, etc., being deposited on the bottom of the platinum dish. The dish is then removed, dried with a clean absorbent cloth, placed in a hot-air oven, and kept at 180° C. for a few minutes. Finally it is placed in a desiccator, allowed to stand therein for five minutes, and then weighed to 0.1 mg. The tare being recorded, the dish is again placed on the water-bath. A 100 c.c. or a 250 c.c. (depending upon the E.C. of the water) stoppered flask is filled with the water to be examined, and about 50 c.c. poured into the dish. When this has nearly all evaporated, a similar quantity is added, and so on until all is in the dish. The flask is then rinsed with a few cubic centimetres of distilled water which are poured into the dish. The dish is allowed to remain about a quarter of an hour on the bath after it appears dry. It is then carefully wiped outside, placed in the air oven at 180° C. for an hour, removed to the desiccator, and, five minutes later, weighed.

It is safer to take a second weighing after further heating for twenty minutes, since, the approximate weight being known, the second weighing can be done rapidly.

180° C. is adopted, because at this temperature magnesium sulphate retains a definite proportion of water, and calcium sulphate loses the whole of its water of crystallisation, the results consequently being much more uniform and satisfactory than at a lower temperature. The results are sufficiently accurate for the quantitative estimation of the saline constituents, and it is very rarely necessary to check the results by converting the salts into sulphates, as described later.

The dish having been weighed, it may be gently heated over a naked Bunsen flame to ascertain whether the residue chars or undergoes other change on heating. Weighing after ignition to ascertain

the "loss" appears to be a waste of time, as it gives no information of any value.

The water residue, after moistening with hydrochloric acid, may be used for examination by the flame test, using a blue glass for detecting potassium, or the spectroscope for the detection of the rarer metals. It may also be used for testing for traces of lead, iron, manganese, or zinc, where the original water gave no decided reaction indicating the presence of these metals.

Certain waters contain magnesium chloride, and, when such is the case, some chlorine is lost during the drying process. A correction may be made for this by estimating the chlorine in the dried residue and adding to the total solids the amount of chlorine lost, less its equivalent of oxygen. As magnesium sulphate retains 1 molecule of water when dried at 180°C ., this is included in the undetermined portion. Calcium chloride is not rendered absolutely anhydrous at 180°C ., nor is magnesium nitrate. Magnesium carbonate also appears to retain a little water, the dried precipitate being a hydrated carbonate. For these and other reasons, the total solids obtained by drying can never exactly correspond with the total of the ions as directly determined.

A confirmation of the analytical results may possibly be obtained by moistening the residue left upon evaporation with dilute sulphuric acid (1 in 4) and carefully heating on a hot plate until fumes are no longer evolved. The residue is then gently ignited and weighed. The result gives the total weight of all the bases as sulphates, plus the weight of the silica. On several occasions, when there was an unusual discrepancy between the total of the saline constituents and the total solids, this process has been adopted.

Another method often used when determining the total solids of water containing MgSO_4 , MgCl_2 , or CaCl_2 , is to add to the water before evaporation a measured quantity of decinormal solution of sodium carbonate, rather more than sufficient to decompose any of the above salts which might be present, and, after weighing the dried residue, to deduct the weight of the sodium carbonate added. Although, as a rule, the total solids as thus determined approach more nearly the total of the saline constituents of the water, and the process of weighing is facilitated, the results are of little more value than those obtained in the usual way.

With unpolluted waters, the results of the direct and indirect determinations closely correspond; it is only with polluted waters that the difference between the total solids and the total of the saline constituents is at all marked, and such waters are rarely worth the trouble of an extended examination.

Some analysts give the total solids without saying at what temperature they are dried; some dry at 100°C ., some at 120°C ., and others 180°C . In all cases some water of hydration is included, but at 180°C . there should be little except what can be calculated; but when CaSO_4 or MgSO_4 are present with much other saline matter, it is difficult to drive off the whole of the water from the calcium sulphate,

and 1 molecule of water always remains attached to the magnesium sulphate at 180° C. If calcium or magnesium chlorides or nitrates are present, they are so hygroscopic that it is practically impossible to obtain an accurate weighing. In these rare cases it is necessary to add sodium carbonate and deduct the weight added from the total weight of the residue. Even with this correction the results are slightly erroneous, as any magnesium present is precipitated as a basic carbonate. Such being the case, it is surprising to see so many analyses in which the figure for total solids is given to the second or third place of decimals. Occasionally, we have some doubt even as to the first place of decimals. The total solids, after estimation, are ignited, and on occasions the loss is put down as organic matter, though some loss may occur in the residue from a water containing no organic matter. This may be due to loss of residual water of hydration, to evolution of CO₂ from carbonates, of oxygen from nitrates, and volatilisation of ammonia salts. There is no reliable method for determining the amount of organic matter, but a rough approximation can be obtained by a process which will be described when considering the analysis of sewage and sewage effluents. Frankland attempted the estimation of the organic carbon and organic nitrogen, but the process has long been discarded. These determinations, however, are rapidly losing their importance; certainly the determination of the "loss on ignition" is of little value save, occasionally, as a check on the results of a full analysis. Information regarding the organic matter can be obtained more decisively, and much more quickly, by the estimation of the ammonia yielded by the organic matter when the water is distilled with a strongly alkaline solution of potassium permanganate, and the determination of the oxygen absorbed from an acid solution of permanganate.

Chlorine in Chlorides

The quantity of chlorine existing as chlorides, whether large or small, can be determined in a very simple manner by the use of a standard solution of silver nitrate, using potassium chromate as an indicator.

Method of Estimation. *Apparatus Required.* Burette graduated in 0.1 c.c. A deep white porcelain dish (200 c.c.) and glass rod.

Reagents Required. Standard solution of silver nitrate, each cubic centimetre of which corresponds to 1 mg. of chlorine. Solution of potassium chromate (5 per cent.).

Process. To 100 c.c. of the water in the porcelain dish add 1 c.c. of the solution of potassium chromate. Run in the silver solution carefully until, after stirring, a faint brick-red colour appears and remains permanent. Then from a graduated cylinder or pipette run in more of the water until the clear yellow tint just reappears. The number of milligrammes of chlorine in 100 c.c. of water, plus half the further amount added, closely approximates to the number of cubic centimetres of silver nitrate used.

When the quantity of chloride present in the sample exceeds 10 parts per 100,000, expressed as chlorine, an aliquot portion of the water should be taken and diluted to 100 c.c. with distilled water.

The reaction involved in the above determination consists, in the first place, in the formation of the white insoluble silver chloride, and when all the chlorine is thus precipitated, the excess of silver is thrown down as red silver chromate. When the silver solution is added to the water containing the potassium chromate, both silver chloride and silver chromate are precipitated; at first the chromate is rapidly decomposed by the chloride remaining in solution, but as the amount of unprecipitated chloride decreases, the decomposition of the silver chromate becomes slower and slower, indicating the approach of the end of the reaction. An excess of silver nitrate must be used to produce the red colour, and this excess varies, within certain limits, with the amount of potassium chromate added. Whilst a deficiency of chromate is to be avoided, an excess is undesirable, as it obscures the delicacy of the end reaction. It is important, therefore, always to use a standard amount of chromate.

The silver solution used is, in the first instance, always in excess of the amount of chlorine present, but when the titration is completed as described, the results are reliable. In the following experiments a solution of pure sodium chloride was used, of such strength that each cubic centimetre corresponded to 1 mg. of chlorine. Various quantities of this solution were diluted with distilled water to 200 c.c.; 100 c.c. were titrated; after adding the silver nitrate, more of the dilution was added until the faint red colour disappeared.

Chlorine in 100 c.c. mlgm.	c.c. of silver nitrate solution used	Amount of water in c.c. corresponding thereto	Chlorine found mlgm.
1.0	1.15	100 + $\frac{20}{2}$	1.05
1.75	1.85	100 + $\frac{15}{2}$	1.75
3.0	3.2	100 + $\frac{10}{2}$	3.1
5.0	5.15	100 + $\frac{5}{2}$	5.05
7.5	7.7	100 + $\frac{3}{2}$	7.6
8.0	8.3	100 + $\frac{3}{2}$	8.1
10.0	10.2	100 + $\frac{3}{2}$	10.0
12.0	12.2	100 + $\frac{3}{2}$	12.0
20.0	20.4	100 + $\frac{3}{2}$	20.1

With proper care it is rarely necessary to concentrate a water before determining the chlorine, but where very great accuracy is desired, water containing less than 1 part of chlorine in 100,000 should be evaporated, 500 c.c. or 250 c.c. being reduced to 100 c.c. Without evaporation, the error need not exceed 0.1 mg. of chlorine. With a little experience the change in colour from decided yellow to a pale brick-red is

readily observed. When coloured waters are being examined, such as those containing peaty matters, the delicacy of the reaction is impaired and treatment of the water is usually necessary. Such waters also have at times an acid reaction, in which case a little sodium bicarbonate must be added before running in the silver nitrate. Sewage-polluted waters, and waters containing traces of sulphuretted hydrogen, can be titrated only after special treatment. This will be referred to in Chapter XIX.

Colouring matter can generally be removed by boiling the water with a little freshly precipitated aluminium hydroxide.

Softened waters containing an excess of lime should be rendered faintly acid with dilute sulphuric acid and the excess neutralised by means of sodium bicarbonate.

As a matter of experience, we find that the addition of a few crystals of zinc sulphate to waters having an alkaline reaction, or an odour of sulphuretted hydrogen, permits of the chlorine being titrated in the great majority of cases without filtration or other treatment.

Waters which have been chlorinated should be examined for free chlorine, but the small amount usually found in chlorinated waters has no effect upon the determination of the chlorides.

Free, Available or Active Chlorine

Free chlorine is not found in natural waters, but is often present as the result of treatment. In the control of water sterilisation by chlorination, it is necessary to determine the free chlorine present in the treated water.

In view of the wide-spread application of chlorination, many samples of water received at the laboratory for chemical analysis contain minute traces of free chlorine. This is particularly the case where the ammonia-chlorine or chloramine process is employed at the waterworks.

Free chlorine may be detected by the blue colour produced in the water on the addition of potassium iodide and starch solution, and by the yellow colour given by ortho-tolidine solution. Neither of these tests is specific for free chlorine, and, in acid solution, the same colour changes may be produced by the presence of other substances in the water, such as nitrites, ferric salts, and manganic salts. In the absence of these substances, the ortho-tolidine test provides a delicate quantitative method requiring no special apparatus. It is the test most commonly employed, and is convenient both at the waterworks and in the laboratory. The solution consists of 0.1 per cent. ortho-tolidine in 10 per cent. hydrochloric acid (see Appendix No. 55).

To 100 c.c. of the water in a Nessler cylinder add 1 c.c. of the above reagent. Mix and allow to stand for five minutes. A perceptible yellow colour develops if the sample contains as little as 0.02 part per million of free chlorine.

The same colour reaction is given by chloramine, but is slower to develop than with chlorine, and the maximum colour is not attained

until after fifteen or twenty minutes' standing in the dark. The colour fades in the course of hours, and disappears more quickly when exposed to sunshine.

The test may be made quantitative by comparing the colour with that of a standard solution of chlorine, but as this is troublesome to make and standardise, Race gives the formulæ (*vide* Chapter XLI.) for two solutions, one of copper sulphate, and the other of potassium dichromate. By diluting these, the colour produced by the tolidine test can be matched and the amount of chlorine thus determined.

The "comparator" type of apparatus is now conveniently used for making free chlorine determinations. A fixed amount of ortho-tolidine solution is added to a specific quantity of the water contained in a standard glass cell or tube. The colour which develops in the presence of free chlorine is matched against tinted glass or celluloid discs, and the appropriate disc gives a direct reading of the free chlorine in parts per million. The British Drug Houses Lovibond "Nessleriser," and the "Hellige Comparator" are apparatus of this type.

Nitrites

The quantity of nitrogen as nitrites found in potable waters rarely amounts to 0.1 part per 100,000, but even this small quantity admits of easy detection and estimation.

Detection of Nitrites. *Presumptive Test. Reagents Required.* Solutions of potassium iodide and of starch. Dilute acetic acid (B.P.). The reaction depends upon the liberation of iodine from the iodide by the nitrous acid. The oxide of nitrogen produced then acts as a carrier of oxygen from the air, and thus a continuous increase in the amount of iodine set free occurs. The reaction is most delicate when the water is saturated with air; hence, before adding the reagents, the water should be thoroughly aerated by agitation.

Process. To 50 c.c. of the aerated water add 1 c.c. of each of the acid, the iodide, and the starch solutions. If no blue colour develops in five minutes, nitrites may be considered to be absent. With 0.1 part per 100,000 of nitrous nitrogen, a dark blue colour is produced instantly, with 0.05 part per 100,000 the colour appears in a few seconds, and with 0.01 part per 100,000 in about thirty seconds. If no reaction is obtained in five minutes, nitrites are either absent, or present in such infinitesimal amount as to be negligible.

Chlorine, manganese, and ferric salts also liberate iodine from potassium iodide, and thus give a positive reaction to this test.

A solution of potassium iodide and a freshly prepared solution of starch may be used, but the reaction therewith is neither so delicate nor so reliable as that with the specially prepared starch solution. Numerous formulæ for starch solutions have been tried, and the one we have found most reliable is given in the Appendix.

Time is an important factor in this reaction. Most waters, if left to stand long enough exposed to the air after the addition of the iodide,

etc., develop a blue tint. It is supposed that the air of a laboratory often contains sufficient nitrite to produce the reaction. For these reasons the result of the iodide test, when positive, should always be confirmed by the test described below.

Naphthylamine Test (Ilosvay's). *Reagents Required.* Solution of sulphanilic acid. Solution of alpha-naphthylamine. Standard solution of sodium nitrite. This is really a modification of Griess's test. It is more delicate, but the results are more affected by variations in the quantities of reagents used.

The examination is conducted in Nessler glasses, adding 2 c.c. of each reagent to 50 c.c. of the water, and allowing to stand a few minutes. If nitrite is present a pink colour develops.

For this confirmatory test, time also is a factor, the colours produced developing slowly when only minute quantities of nitrites are present, but the results are not affected by the presence of ferric or manganic salts.

The rapidity of the reaction depends, up to a certain point, upon the amount of free acid present, and an excess of acid interferes with the delicacy of the reaction. For this reason the proportion given should always be observed, especially if a quantitative experiment is to be made, and it is always desirable to make a blank experiment to test the distilled water and reagents. If a tint does not appear in ten minutes after adding the reagents to the water, nitrites may be said to be absent. For comparative purposes, no standard which has been prepared for more than half an hour should be used. The exact amount of nitrite present is rarely estimated. If the reagents give a reaction within a few seconds, the quantity present may be expressed as a "distinct trace." If it takes a minute or two to show itself, a "trace" may be said to be present; whereas if the colour only develops towards the end of ten minutes, the amount may be expressed as a "minute trace." This really gives all the information desired.

With 0.001 part per 100,000 of nitrous nitrogen (N), this test gives a distinct reaction in two minutes on the average. If more than two minutes elapse before the pink colour appears, less than this amount must be present. The colour appears almost immediately if 0.005, or more, part per 100,000 are present, and the limit of delicacy appears to be approximately 0.0001 part per 100,000.

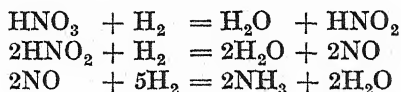
Now that chlorination is extensively used for the purification of water, examination for free chlorine should be made in any sample giving a reaction with iodide and starch.

Nitrates

An analysis without a determination of the nitric nitrogen cannot be considered as sufficiently complete for sanitary purposes, although it is not always necessary to make an exact quantitative test. Much uncertainty, however, is caused by the use of such terms as "trace," "minute trace," etc., and it is desirable, therefore, that the quantity be numerically expressed or that the term used be qualified by a numerical limit.

In no other determination do results differ so widely. On more than one occasion we have had to give an opinion upon a water which had been submitted to various well-known analysts. Though the other determinations recorded in the analyses have been concordant, the nitric nitrogen has varied considerably. This has not been due to any change in the character of the water, as in some instances the samples were taken at the same time. The differences appear to be due to the methods employed. The only process in which we have confidence is one in which the nitrates are reduced to, and determined as, ammonia, and therefore it is the only one given here.

The hydrogen necessary for the reduction may be obtained by the action of either an acid or an alkali upon the zinc-copper couple. The reaction probably takes place in three stages :—



The test can be applied in various ways, but, in order to ascertain the quantity of water to be used, it is advisable to make the following preliminary rough estimation of the amount of nitrates present.

To 50 c.c. of the water in a Nessler cylinder add 1 c.c. of dilute sulphuric acid (1 in 4), 1 c.c. of the solution of starch, and a minute crystal of potassium iodide. No indication of nitrites being found, add a few milligrammes of zinc dust previously shaken with a little distilled water, and mix thoroughly. When nitrates are present in small quantities a blue colour slowly develops; with larger quantities the colour appears more quickly, and when the nitrates present exceed 1 part of nitric nitrogen per 100,000 the colour appears almost instantly. With solutions of potassium nitrate of various strengths the following results were obtained :—

Nitric nitrogen
parts per 100,000.

0.10	A distinct blue colour appeared in a little under one minute.
0.25	„ „ about half a minute.
0.50	„ „ from eight to ten seconds.
1.00	„ „ three or four seconds.

In many cases this rough method gives sufficiently approximate results without further labour. Care should be taken to add just sufficient zinc dust to cause a slight turbidity. If the water contains nitrites, this preliminary test is useless.

When the colour takes some minutes to make its appearance, 100 c.c. of the water are used for the final determination. When the colour appears almost instantly, 10 c.c. are sufficient. When the amount of nitrate appears to be very excessive, 5 c.c. may suffice.

1. Reduction of the Nitrate to Ammonia in the Presence of Acid.

Apparatus Required. Small flask of 50 to 120 c.c. capacity. The usual distilling apparatus.

Reagents Required. Granulated zinc. Solution of copper sulphate. Dilute hydrochloric acid. Solution of caustic soda free from ammonia,

or solution of pure sodium carbonate. Nessler solution and standard solution of ammonium chloride.

Place in the small flask sufficient granulated zinc to cover the bottom. Wash the zinc first with sulphuric acid (1 in 4), then with distilled water. Cover the zinc with the solution of copper sulphate (*vide* Appendix), and allow to stand for a few minutes until the zinc is completely covered with a black deposit of copper. Again, wash with several quantities of distilled water, taking care not to remove the coating of copper. Having, by the preliminary experiment, ascertained how much of the water to be examined should be used, measure this quantity into the flask. Acidulate with 1 or more drops of dilute hydrochloric acid (1 in 6) and place in the incubator at 37° C. for at least an hour. If necessary, add a little more acid, so as to maintain a slight but visible evolution of hydrogen in exceedingly minute bubbles. In about an hour the whole of the nitrates and nitrites will be reduced to ammonia.

Whilst this reduction is taking place, about 250 c.c. of distilled water to which 5 c.c. of caustic soda solution (10 per cent.), or of saturated solution of sodium carbonate, have been added are placed in a distillation flask and 50 c.c. of water distilled over. This removes any free ammonia from the apparatus and the alkaline water. Now pour the water which has been digested with the copper-zinc couple into the flask, using a little pure distilled water for rinsing the zinc and taking care not to introduce any of the metal into the distillation apparatus.

Distil over 50 c.c. and estimate the ammonia present by the process of Nesslerisation as described on p. 239. If the distillate contains more than 0.05 of ammonia, a second 50 c.c. should be distilled, and the ammonia therein estimated.

From the ammonia figure thus obtained the equivalent amount of nitrogen is calculated.

The amount of free ammonia in a potable water is usually so small as not to affect the results appreciably, but should a water contain much ammonia, the necessary correction can easily be made, or the free ammonia may be boiled off before introducing the water into the reducing flask.

The following results were obtained with solution of potassium nitrate of known strength :—

Nitric nitrogen parts per 100,000.		Nitric nitrogen found.
1.40	(Digested thirty minutes)	1.45
1.40	(Digested sixty minutes)	1.40
1.00		0.98
0.56		0.56
0.46		0.49
0.32		0.32
0.20		0.198
0.10		0.108
0.10		0.104
0.05		0.055

2. The following method dispenses with distillation and gives very good results.

Proceed exactly as in the first process for the reduction of the nitrates, but instead of distilling, dilute to 49 or 99 c.c. and add a dilute solution of caustic soda or potash drop by drop until all the zinc hydroxide is precipitated and the reaction is faintly alkaline to phenolphthalein. Filter through a washed paper or allow to clear by subsidence; take an aliquot part and Nesslerise. The following table shows the results obtainable by this process, using a solution of potassium nitrate in distilled water :—

Nitric N. in parts per 100,000.	N. found.	Nitric N. in parts per 100,000.	N. found.
0.05 . . .	0.055	0.80 . . .	0.77
0.10 . . .	0.108	1.00 . . .	0.98
0.16 . . .	0.14 and 0.15	1.60 . . .	1.51
0.20 . . .	0.198	3.92 . . .	3.95
0.40 . . .	0.41		

Certain waters, however, are difficult to compare, becoming slightly turbid on the addition of the Nessler solution, or giving a different colour from that obtained with distilled water. In such cases, the use of oxalic acid, instead of hydrochloric acid, in the reducing process possesses an advantage. The process is very rapid, and when a number of waters have to be examined and an accurate estimation of the nitrates is not necessary, it answers extremely well.

The nitrogen in the nitrites, if present, must be separately estimated and deducted from the results obtained. The nitrogen in the free ammonia must also be removed or deducted, if the water contains sufficient to affect the results.

The following experimental results show the relative value of various processes. An assistant prepared 500 c.c. of a solution by adding to pure distilled water a little sewage, free from nitrates, some calcium chloride, and magnesium sulphate. To this he added a carefully measured volume of solution of potassium nitrate, each cubic centimetre corresponding to 1 mg. nitric nitrogen. The amount of nitrate added was unknown to the analyst. The results obtained by the various processes were as under :—

Process employed	Amount of water used	Nitrogen found parts per 100,000
Indigo	10 c.c.	1.3
"	20 "	1.37
Phenolsulphonic acid	10 "	1.5
" "	5 "	1.2
Copper-zinc without distillation	10 "	1.23
" "	10 "	1.13
" "	10 "	1.16
Copper-zinc with distillation	10 "	1.16
" "	10 "	1.21

The results varied, therefore, from 1.13 to 1.5 parts per 100,000.

The assistant had added to the $\frac{1}{2}$ litre of water 5.8 c.c. of nitrate solution, corresponding to 1.16 N. parts per 100,000.

Subsequently a sample of water received for analysis was found to contain an unusual amount of nitrates and was examined by these several methods.

The results obtained were as under :—

Process used.	Nitrogen parts per 100,000.
Zinc-copper with distillation	12.3
Zinc-copper without distillation	11.6
Indigo	12.0
Phenolsulphonic acid	10.2

We regard the first as being most nearly correct, and the last as the most erroneous.

Phosphates

As has already been stated, phosphates are rarely present in potable waters in appreciable quantities, and their detection and estimation afford no indications of value in regard to pollution.

When a water is examined for phosphates, it often suffices to ascertain their absence, or presence in "minute traces," "traces," or "heavy traces" with the numerical limit appended.

The following process is reliable, since it ensures the removal of silica which otherwise may mislead by giving a reaction which can be mistaken for a "minute trace" of phosphate. It is due to neglect of this precaution that the presence of traces of phosphates is sometimes erroneously reported.

Reagent Required. Solution of ammonium molybdate in nitric acid.

Process. Strongly acidulate 100 c.c. of the water with nitric acid and evaporate to dryness in a porcelain basin. Heat the residue to 120° C. in the hot-air oven for a quarter of an hour, then dissolve in 3 c.c. of distilled water to which 2 or 3 drops of nitric acid have been added. Place 5 c.c. of the ammonium molybdate solution in a test tube and heat to about 60° C. Pour in the solution of the water residue (unless distinctly turbid it is unnecessary to filter) and set aside in a warm place for about fifteen minutes. The development of a yellow colour but no precipitate indicates a "minute trace," a decided turbidity "a trace," and a distinct precipitate a "heavy trace," of phosphoric acid. These terms correspond with approximately 0.01, 0.1 and 0.5 part per 100,000 respectively of phosphate, as PO_4 .

If the total solids in the water have been estimated by the evaporation of 100 c.c. in a platinum dish, the residue, after solution in a little dilute nitric acid, may be transferred to a small porcelain basin for evaporation to dryness, etc., and used for this determination. If the evaporation in the presence of acid were conducted in the platinum dish, the chlorine liberated by the action of the nitric acid on the chlorides present would attack the metal, and a trace of platinic chloride

be formed, possibly sufficient to impart a faint yellow tint to the solution.

The amount of phosphoric acid present may be approximately estimated by using a standard solution of sodium phosphate, of which 1 c.c. = 0.1 mg. of the anion PO_4 , and diluting various amounts of this with water to 3 c.c., adding 2 or 3 drops of strong nitric acid, and proceeding as already described. These standards can then be compared with the results obtained with the water under examination.

A much simpler process, devised by Denigès, is a colorimetric one. It has been slightly modified by Florentin and by Atkins (*Journal of Marine Biology*, vol. xiii, No. 1), and is so delicate that 0.0001 mg. may be detected in 100 c.c. of water.

Reagents Required. 1. A strongly acid solution of molybdic acid.

2. A freshly prepared solution of stannous chloride.

3. Standard phosphate solution. (*Vide Appendix.*)

To 100 c.c. of the sample in a Nessler cylinder add 2 c.c. of the molybdic acid solution and 0.5 c.c. of the stannous chloride solution. In the presence of phosphates a blue colour develops, and can be matched by a suitable dilution of the standard phosphate solution. The extremes found by Atkins were 0.00002 part per 100,000 in a moorland water, and 0.017 part per 100,000 in a good well water.

Hardness or Soap-destroying Power

The hardness or soap-destroying power of a water depends almost entirely upon the amount of calcium and magnesium salts present. Occasionally there is sufficient zinc or iron present in the form of carbonate or sulphate to increase the soap-destroying power, and the presence of free carbonic acid gas or unusually large quantities of sodium chloride is not without effect. The unit of soap-destroying power is one-tenth of that possessed by 100 c.c. of water containing 10 mg. of calcium carbonate (or its equivalent of calcium chloride) in solution. The amount of soap destroyed by 1 mg. of that salt is not exactly one-tenth of that destroyed by 10 mg., hence tables have been compiled in an attempt to correlate soap destruction with the calcium and magnesium content of water. There are, however, so many factors which interfere with the soap test that such tables serve no useful purpose. The unit above suggested, and generally adopted, has a definite meaning and practical use. A water of 8 degrees of hardness will waste approximately twice as much soap as one of 4 degrees, and half as much as one of 16 degrees, and so on more or less proportionately. Beyond this it means nothing definite, but it gives a rough idea of the amount of calcium and magnesium salts present, and this rough approximation is very often quite sufficient for the purpose of the analyst. If insufficient, it is more satisfactory to determine the amount of these salts by the appropriate methods than to attempt to calculate it from the results of the soap test.

The hardness left after boiling may or may not be entirely due to sulphates and chlorides, since the whole of the carbonates is certainly not deposited during the boiling process, neither magnesium carbonate nor calcium carbonate being quite insoluble in water.

Estimation of the Total Hardness. *Reagent.* Standardised solution of soap (see also p. 784).

Apparatus. A 20 c.c. burette and a stoppered 200 c.c. bottle.

Process. Place 100 c.c. of the water in the bottle and run in the soap solution 1 c.c. at a time until, after vigorous agitation, a lather is formed which persists for five minutes when the bottle is laid on its side. The lather should equal that produced when 1 c.c. of the soap solution is shaken with 100 c.c. of carbonic-acid-free distilled water. When a lather begins to form, the soap solution can be added in smaller quantities until the requisite permanency is attained. If the hardness of the water exceeds 14 parts per 100,000, the operation must be stopped and recommenced, using 50 c.c. or 25 c.c. of the original water diluted to 100 c.c. with distilled water. To shorten the process, it has been suggested that, at first, a rough experiment should be made, adding the soap solution 5 c.c. at a time. In the second experiment the soap solution is run in more boldly at first, and afterwards in small quantities. The results, however, do not always correspond with those obtained when the soap solution is added more gradually, and the latter method is to be preferred.

As 1 c.c. of soap solution is required to produce a lather in the absence of lime and magnesium salts, the degree of hardness or soap-destroying power is one less than the number of cubic centimetres of soap solution used. When a diluted water has been used, this, of course, gives the hardness of the dilution, and the hardness of the water will be twice or four times that of the dilution, according to whether 50 c.c. or 25 c.c. of the water have been used.

Waters which contain a considerable quantity of magnesium salts may form a distinct curd with the soap. Such waters require copious dilution. Even then the end reaction is difficult to determine, and much experience is required to obtain concordant results. Sometimes a lather will appear to be permanent upon standing, yet, if the solution is gently agitated, it disappears, and cannot be reproduced until more soap has been added. In such cases, the addition of soap solution must be continued until the lather is really permanent for five minutes, and is nearly as voluminous as it was at first.

Determination of the Permanent and Temporary Hardness. For this an Erlenmeyer's flask of 200 c.c. capacity is required. One hundred cubic centimetres of the water are placed in the flask and boiled gently for half an hour, distilled water being added from time to time to replace that lost by evaporation.¹ The water is then allowed to cool, passed through a filter paper, made up to the original volume, and the hardness determined in the manner just described. This is the per-

¹ If the evaporation proceeds too far, sulphate of calcium may be deposited and the results vitiated.

manent hardness, and the difference between it and the total hardness is the temporary hardness.

As previously stated, the temporary hardness is that part which is removed by boiling, and it does not correspond to the whole of the carbonates of calcium and magnesium present, since, after boiling, the water retains a trace of calcium and magnesium carbonate in solution.

The temporary hardness is often estimated from the amount of combined carbonic acid in the water, in the manner described in the section relating to that determination. The equivalent of CaCO_3 being ascertained, this is regarded as the temporary hardness, and the difference between this and the total hardness gives the permanent hardness. The results so obtained may differ from those given by the methods described above, especially if the water contains magnesium carbonate. When waters contain sodium carbonate, as is very often the case in the deep well waters of Essex and elsewhere, the process is inapplicable. It is best, therefore, to make a complete analysis.

An alternative method of hardness determination is given in the Appendix, No. 18.

Further reference to this subject will be found in Chapter XX.

Ammonia

The so-called free ammonia found in nearly all waters exists probably in combination with some acid, usually carbonic, but, upon boiling, any carbonate present causes its expulsion as ammonium carbonate. A little ignited sodium carbonate (a fraction of a gram), or a few drops of 10 per cent. sodium hydroxide are added to facilitate the removal of ammonia, and render any acid water alkaline.

The distillation must be carried out in a laboratory free from fumes of ammonia or any other vapour or gas given off in laboratory operations. Traces of formaldehyde, for example, vitiate the results of the ammonia determinations.

Reagents Required. An abundance of ammonia-free distilled water. Standard solution of ammonium chloride, 1 c.c. = 0.01mg. of ammonia. Nessler solution.

Apparatus. Retort or boiling flask and condenser. 50 c.c. and 100 c.c. Nessler cylinders. Burette or pipettes for the standard ammonia solution. Pipette holding about 2 c.c. for measuring the Nessler solution. 500 c.c. measuring flask.

Fig. 21 shows the apparatus with double condenser surface used in our laboratory.

For measuring the Nessler solution and mixing it with the water, use a 2 c.c. pipette which has been cut so that it admits and discharges very freely. When the bulb is inserted in the Nessler solution, it immediately fills, and by closing the upper end with the finger the requisite quantity can be readily removed and discharged. This avoids any disturbance of the deposit which usually forms at the bottom of the bottle containing the reagent.

Process. Introduce into the thoroughly cleaned flask 500 c.c. of the water to be examined, and distil. The distillation at first should be

slow and kept as regular as possible. If there is any doubt about the apparatus being ammonia-free, or if any ammonia has been recently used in the laboratory, it is best to put a little good tap water into the flask and distil until the distillate, when tested with Nessler reagent, proves to be quite free from ammonia. The flask may be cleansed by rinsing first with a little strong hydrochloric acid, and afterwards with successive quantities of good tap water until every trace of acid has been removed.

The distillate is collected in cylinders marked at 50 c.c. When the first 50 c.c. has come over, about 2 c.c. of the Nessler solution are added to it and well mixed. Into a second similar cylinder a measured quantity of the ammonium chloride solution is diluted to 50 c.c. with ammonia-free water, and to the mixture 2 c.c. of the Nessler solution are added. If the two liquids after standing two or three minutes have approximately the same tint, the standard will serve for the estimation. If there is a marked difference, fresh standards must be made weaker or stronger as the case may be, until one of approximately equal strength is obtained. The two cylinders used must be of the same diameter, so that the columns of liquids are exactly the same height. If one solution is a little darker than another, this is transferred to a graduated cylinder, and then poured back slowly until the tint of the column exactly corresponds with that of the paler. The strength of either solution can then be readily estimated. For example, the distillate (50 c.c.), after addition of Nessler solution, acquires a colour a little darker than that of a standard containing 5 c.c. of ammonium chloride solution (0.05 mg. NH_3). Transferred to the measuring cylinder, the volume of the liquid is 52 c.c., and 48 c.c. poured back gives a column similar in depth of colour to the standard.

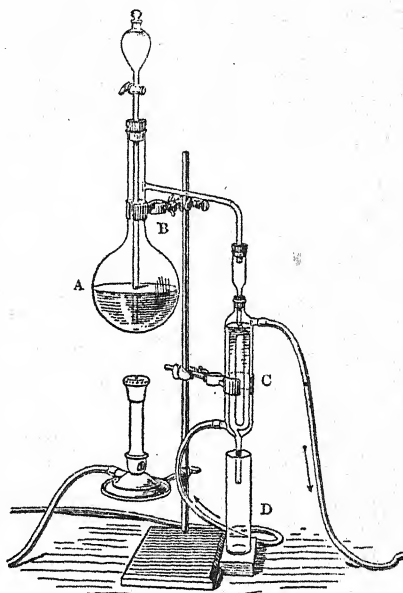


FIG. 21. A, flask with tubulure, holding about 600 c.c., and supported by a clamp, B; C, glass vertical condenser with support; D, Nessler cylinder.

The ammonia in the distillate $\frac{52}{48} \times 0.05 = 0.054$ mg.

Assuming, on the other hand, that the standard solution is a little darker, and that 48 c.c. = the 52 c.c. of distillate and Nessler solution, the ammonia in the distillate would then be $\frac{48}{52} \times 0.05 = 0.046$ mg.

If the distillate contains much more than 0.05 mg. ammonia in the 50 c.c., it cannot be very accurately Nesslerised. If great accuracy is desired, it is better to start afresh and distil 250 c.c. and use an aliquot part of the distillate. To avoid this loss of time, it is well to Nesslerise a little of the water without distillation. If the addition of the Nessler solution gives a visible yellow tint, it is evident that the concentrated distillate will require dilution to permit of the ammonia being estimated.

If the first 50 c.c. contains not more than 0.02 or 0.03 mg. of ammonia, the second 50 c.c. is usually ammonia-free, but a second and a third 50 c.c. should be collected and examined. The residue left in the flask can be used for estimating the amount of ammonia produced by the action of a strongly alkaline solution of potassium permanganate upon the organic matter in solution, as described in the next section. This ammonia is usually spoken of as "albuminoid" ammonia.

On the Continent this latter process is but rarely used, and the free ammonia is generally estimated, without resorting to distillation, by the following process:—

Requisites. 250 c.c. stoppered flask and a solution of sodium hydroxide and carbonate (containing about 5 per cent. of each), previously boiled, so as to free it from all traces of ammonia. About 200 c.c. of the water are introduced into the flask, and 5 c.c. of the alkaline solution added. The stopper is then inserted, the flask well shaken and set aside for about twelve hours. At the end of this time the calcium and magnesium salts are deposited, and portions of the clear liquid can be drawn off by means of a pipette and the ammonia directly estimated by the addition of Nessler solution in the manner described above.

Another method for the direct estimation of free ammonia consists of adding to the water 0.5 c.c. of a 10 per cent. solution of sodium hexametaphosphate prior to the addition of Nessler solution. This prevents the deposition of calcium and magnesium salts when the alkaline Nessler reagent is added, and so maintains a bright solution for matching with standards.

Many waters can be Nesslerised without even this preliminary treatment, but the results are not nearly so accurate as when the ammonia is concentrated by distillation. For some purposes, however, the information obtained may be sufficient.

The amount of free ammonia in 500 c.c. having been determined by distillation, the amount present in parts per 100,000 or in parts per million is easily calculated and is frequently expressed in terms of nitrogen as ammoniacal nitrogen.

Some waters yield a distillate having a decided odour and giving with the Nessler solution a colour slightly different from that yielded by ammonia. These waters probably contain traces of compound ammonias, and are always of a suspicious character.

"Albuminoid" Ammonia

The process adopted for obtaining this rough index of the amount of organic matter in solution is always conducted with the water from

which the free ammonia has been driven off by distillation, and the ammonia produced by the action of the permanganate is estimated in the distillate in the manner just described. The apparatus required is that which is used for the free ammonia determination, and the only additional reagent is a strong alkaline solution of potassium permanganate. After removing the 150 c.c. of the water by distillation in estimating the free ammonia, there remain in the flask 350 c.c. of the concentrated water. A further 100 c.c. are distilled off, and to the residue 50 c.c. of the alkaline solution are added, and the distillation slowly resumed. Three successive 50 c.c. are distilled and the ammonia contained therein estimated. This represents the amount yielded by the 500 c.c. of the water, and is frequently expressed in terms of nitrogen as albuminoid nitrogen.

The water, after the addition of the alkali, often boils intermittently, and is then said to "bump."¹ This may easily lead to a loss of ammonia, or to fracture of the flask. The "bumping" may generally be avoided by introducing into the flask a few small pieces of recently ignited pumice, or adding short pieces of capillary glass tubing, each of which has been sealed at one end.

There are numerous modifications of these processes for determining the free and albuminoid ammonia, all devised with a view to increasing the accuracy of the results. These refinements detract from the simplicity of the process without any compensating advantage. The minute errors avoided are quite inconsequential in interpreting the results, as indicated in the section dealing with the interpretation of analysis:

A stoppered retort and Liebig's condenser can be used, but the arrangement is cumbersome. The apparatus (Fig. 21) takes up little space and is very convenient. Care should be taken to employ rubber stoppers and tubing which have been used for no other purpose, and to be certain that the whole apparatus is ammonia-free. If the apparatus has not been used for a few days, it is always advisable to distil a little clean water until the distillate is ammonia-free, and then rinse out the flask with pure distilled water before introducing the water to be examined.

The following method has been described by W. H. Kitto² for the estimation of albuminoid ammonia without distillation.

One hundred c.c. of the water are placed in a 250 c.c. flask and 1 drop of concentrated sulphuric acid added, followed by 0.05 gram of ammonia-free potassium persulphate. The neck of the flask is covered and it is then suspended in boiling water for twenty minutes. Nesslerisation is then carried out directly on an aliquot portion of the water, and the result represents the total ammonia, *i.e.*, both free and albuminoid. The deduction of the free ammonia, which is also estimated directly as previously described, gives the albuminoid ammonia

¹ If the alkaline permanganate is added quickly after the free ammonia has been distilled off the "bumping" seems to be much less troublesome.

² *Analyst*, 1938, 63, 744.

figure. This method is subject to the same limits of accuracy as indicated when describing the determination of free ammonia by direct Nesslerisation.

Estimation of the Organic Nitrogen

For reasons previously given, few chemists prefer to estimate the total nitrogen in the organic matter present in a water. The determination, if properly made, is tedious and troublesome, and the results are of no greater value than those obtained by the simpler processes for the estimation of the albuminoid ammonia. The safety of a water does not depend upon its containing a little less or a little more nitrogenous matter; it may contain relatively large amounts and yet be perfectly wholesome, or it may contain very small amounts and yet be dangerously polluted. Neither the albuminoid ammonia nor the total nitrogen determinations can be depended upon to detect minute quantities of sewage in water, and when more information is wanted than can be obtained by the ordinary methods of chemical analysis, it should be obtained by a bacteriological examination.

The process requires the use of special flasks, very pure concentrated sulphuric acid, and pure sodium hydroxide. A blank experiment should be made with the reagents used and the ammonia obtained deducted from that found in the final distillate from the water examined.

Five hundred cubic centimetres of the water are introduced into the ordinary distillation apparatus and the distillation continued until only about 100 c.c. remain. This is transferred to a Kjeldahl flask, and 10 c.c. of the pure concentrated sulphuric acid added. Evaporation is continued on a sand bath in a fume chamber until acid fumes are given off and the liquid has acquired a pale yellow colour. A few milligrammes of powdered potassium permanganate are then added and the heating continued until the liquid is of a decided green colour. It is then allowed to cool, and, after the addition of 200 c.c. of ammonia-free distilled water, it is transferred to the distillation flask, into which 100 c.c. of caustic soda solution (*vide* Appendix) are poured. The ammonia formed by the action of the strong acid on the organic matter is then distilled off and Nesslerised in the usual manner. Alternatively, the Nessler cylinder, into which the water is to be distilled, may contain a little distilled water, slightly acidified with hydrochloric acid, and the end of the condensation tube made to terminate below the surface of the acidulated water. By this method, and by distilling the first 50 c.c. very slowly, any loss of ammonia can be avoided. When 200 c.c. have distilled over, 50 c.c. of the distillate, rendered alkaline if the latter method of collection has been used, may be Nesslerised. The ammonia found in the 50 c.c., multiplied by 4, gives the amount of ammonia obtainable from 500 c.c. of the water, and to convert this into nitrogen it is only necessary to multiply by 0.824. The amount found in the blank experiment

being deducted, the nitrogen derived from the organic matter in the water is known.

Example. A water which yielded 0.008 part per 100,000 of albuminoid ammonia was submitted to Kjeldahl's process. The blank experiment showed that the ammonia yielded by the chemicals was 0.035 mg.

Five hundred cubic centimetres of water were taken, and the ammonia found in 50 c.c. of the distillate of 200 c.c. was 0.035 mg., or in the whole 200 c.c., 0.140 mg. From this had to be deducted 0.035 mg. found in the chemicals, leaving 0.105 mg. as being derived from the 500 c.c. of water. This corresponds to 0.087 mg. of nitrogen. The organic nitrogen, therefore, was 0.174 mg. per litre, or 0.0174 part per 100,000.

The method is more scientific than that of determining the albuminoid ammonia, but notwithstanding its tedious character, it would long since have been generally adopted had it possessed any advantage over the less scientific but simpler process.

The nitrogen in nitrates and nitrites is not included in this determination, nor does its presence in such quantities as are ordinarily found in potable waters appear to affect the results. Many modifications have been suggested, all introducing additional possible sources of error and complicating the process; it is not necessary, therefore, to make any further reference to them.

Oxygen Absorbed from Permanganate

All waters, when strongly acidulated with sulphuric acid and mixed with a little permanganate of potash, absorb from this salt more or less oxygen, the amount of which can be determined if the amount of available oxygen in the permanganate added is known and the amount left after the action of the water is determined. The difference gives the oxygen absorbed by the constituents of the water. Some very pure waters absorb very little indeed, less than 0.1 mg. per litre, while others containing organic matter in solution absorb many times this amount. Although, strictly speaking, it is an index of neither the quantity nor the quality of the organic matter present, yet, as the amount absorbed varies in different waters, being usually very small in pure waters and comparatively large in impure waters, the determination is not without value. Certain inorganic substances occasionally found in waters, such as nitrites, ferrous salts, and sulphides, also reduce permanganates. These act on the permanganate with rapidity, whilst the organic matter acts very slowly. When any of these substances are present, two determinations are generally made; one to ascertain the amount of oxygen absorbed by the inorganic matter, and the other to estimate the total oxygen absorbed, and the difference is taken as being the amount consumed by the organic matter.

The total oxygen absorbed varies greatly in the same water, the chief factors being time and temperature, but the concentration of the

reagents and the intensity of the light are other important factors in carrying out the test. Therefore, if results are to be comparable, they must be obtained under identical conditions. Some chemists maintain the water at 27°C . for three hours, whilst others prolong the time to four hours. Some carry out the test at room temperature, considering the temperature of the laboratory to be sufficiently constant, whilst others prefer a temperature of 37°C . or 100°C ., and reduce the time to fifteen minutes or one hour. Continental chemists make very little use of the process, and some prefer to use an alkaline rather than an acid solution. We have tried all the processes in use and many others which have been suggested, but have not found that any yield more reliable results than the following slight modification of the process recommended by the late Dr. Tidy, which was a modification of Forchammer's method. The method differs only from Tidy's in that the water is kept at 37°C . instead of 27°C ., because that is the temperature of the ordinary warm incubator used in most laboratories. Also, in the incubator, the absence of light is secured, so that the conditions are easily kept uniform. The procedure generally adopted, however, is to maintain the water at 27°C . for four hours, and the figure obtained is practically the same as that obtained at 37°C . in three hours.

Apparatus and Reagents Required. Standard solution of potassium permanganate, 1 c.c. = 0.1 mg. available oxygen. A very dilute solution of sodium thiosulphate. Solutions of potassium iodide and of starch. Solution of sulphuric acid (1 : 4). Stoppered bottles or flasks holding about 400 c.c. Burettes, pipettes, etc.

Process. 250 c.c. of the water to be examined, warmed to 27°C ., are measured into one of the bottles or flasks, which should have been previously cleaned with acid, etc. To this are added 10 c.c. of the solution of potassium permanganate and 10 c.c. of the sulphuric acid, and, after insertion of the stopper, the bottle is placed in the incubator. It is left there for four hours, with examination from time to time to see that a decided pink colour remains. If the colour tends to disappear, add a second 10 c.c. of permanganate solution, as the reagent should always be present in marked excess. A blank experiment is made with the reagents added to distilled water and placed in the incubator, or water-bath, with the waters under examination. On completion of the four hours' period, the samples are cooled to room temperature and individually treated, first by adding a crystal or two of potassium iodide, and then by titrating with thiosulphate solution, using starch solution as an indicator. Cooling and uniformity of temperature must be maintained since the temperature affects the end-point of the titration.

If it is desired to estimate the oxygen absorbed by the inorganic matter, add to 250 c.c. of the water the acid and permanganate as before. The mixture is allowed to stand for three minutes, and the un-reduced permanganate then estimated. In examining potable waters this determination is rarely required.

The following are examples of results obtained with various waters:—

1. A deep well water of known purity.

The thiosulphate solution, on standardising, required 28.7 c.c. to decolourise the iodine liberated by 10 c.c. of the permanganate solution.

The water, after the addition of acid and permanganate and being maintained for three hours at 37° C., required 27.6 c.c. of thiosulphate solution.

$$28.7 : 1 :: (28.7 - 27.6) : x \text{ oxygen absorbed by the}$$

$$250 \text{ c.c. of water.}$$

$$x = 0.038 \text{ mg.}$$

corresponding to 0.15 mg. per litre, or 0.015 part per 100,000.

2. A peaty moorland water, free from suspicion of manurial or sewage contamination.

Thiosulphate solution 30.1 c.c. = 10 c.c. permanganate. After oxidation, the thiosulphate solution used = 16.4 c.c.

$$30.1 : 1 :: (30.1 - 16.4) : x = 0.455 \text{ mg.,}$$

or 1.82 parts per million, or 0.182 part per 100,000.

3. A shallow well water undoubtedly contaminated by leakage from house drain.

Thiosulphate solution 29 c.c. = 10 c.c. permanganate. After oxidation, the thiosulphate solution used = 18.2.

$$29 : 1 :: (29 - 18.2) : x = 0.372,$$

or 1.49 parts per million, or 0.149 part per 100,000.

The general formula for the calculation is—

$$\frac{a - b}{a} \times 0.4 = \text{parts per 100,000,}$$

where a = the number of cubic centimetres of thiosulphate solution equivalent to 10 c.c. of the permanganate solution, and b = the number of cubic centimetres of the thiosulphate solution used at the end of the incubation. If 20 c.c. or 30 c.c. of the permanganate solution have been added, then the numerator becomes $2a - b$ or $3a - b$.

Results obtained under one set of circumstances cannot be compared with those obtained under others. The oxygen absorbed by the same waters varies, as has been stated, and the effects of certain of the factors influencing the results are shown in the following experiments.

Example 1

TAP WATER CONTAINING 0.1 PER CENT. OF SEWAGE EFFLUENT.

OXYGEN ABSORBED IN PARTS PER 100,000

4 hours at room temperature (about 18° C.)	0.0262
4 hours at 37° C.	0.0303
1 hour at 100° C.	0.1520

Example 2.—TAP WATER

4 hours at room temperature	.	.	.	.	.	0.0151
4 hours at 37° C.	.	.	.	.	.	0.0262
15 minutes at 100° C.	.	.	.	.	.	0.0840

Example 3

	Polluted well-water.		Peaty water.		Tap-water + 5 per cent. of sewage effluent.
4 hours at 37 C.	0.364	...	0.163	...	0.061
15 minutes at 100°C.	0.740	...	0.300	...	0.132

The effect of exposure to sunlight on the amount of oxygen absorbed varies considerably with different waters. With very good waters absorbing little oxygen the difference produced is slight, but in the presence of organic matter the result of exposure is to increase the amount of oxygen absorbed. A water to which permanganate has been added, and which remains pink and bright in the dark, often becomes brown and turbid if exposed to bright sunlight. The results obtained by different exposures are shown in the following table. All the experiments were made as nearly as possible at the same temperature, the bottle in the dark being contained in black paper or in a cardboard box, side by side with the exposed bottle.

OXYGEN ABSORBED IN THREE HOURS IN PARTS PER 100,000

	In incubator 37° C.	In dark at room temperature	Exposed to bright light at room temperature
A well-water containing vegetable matter .	—	.058	.186
Chalk spring water .	.116	.072	.165
An impure water .	—	.179	.233
Filtered river water .	—	.0107	.0131
Filtered river water .	—	.0132	.0166

Many waters absorb more oxygen from a strongly alkaline solution of permanganate than from an acid solution, and at one time we thought that this was especially the case when the waters were sewage-polluted. A long series of experiments, however, demonstrated that this difference could not be depended upon to distinguish between "recent" and "previous" sewage pollution, or between organic matter of vegetable or animal origin.

In these experiments the oxygen absorbed in the acid solution was determined in the manner already described, after standing four hours at 27° C. The alkaline solutions were made by adding 10 c.c. of 20 per cent. solution of sodium hydroxide in place of the acid, and, after standing four hours at 27° C., they were rendered acid by the addition of dilute sulphuric acid, the titration with thiosulphate being completed in the usual way.

IN PARTS PER 100,000

	Oxygen absorbed from acid per- manganate	Oxygen absorbed from alkaline permanganate
Dilute infusion of deal shavings . .	1.71	1.66
" " " " . .	.528	.532
Infusion of decayed leaves . .	.084	.099
" " " " . .	.122	.132
" " " " . .	.160	.144
" " " " . .	.128	.124
Water plus urine . .	.385	.180
" " " " . .	.224	.212
" " " " . .	.328	.208
" " " " . .	.332	.296
" " " " . .	.256	.164
Sewage-polluted river-water . .	.540	.700
" " " " . .	1.36	1.51
Tap-water . .	.058	.053
Tap-water + sewage effluent . .	.288	.362

Similar experiments made with alkaline solutions of different strengths, and with alkaline carbonates instead of hydroxides, all tended to prove that the results were of no value in indicating the nature of the organic matter. Also, the processes possessed no advantage over the one usually employed, and were more troublesome to perform.

Where river waters are collected for storage preparatory to treatment, it is usual to make an examination for colour and turbidity, in order to decide when the water should be excluded. It might, however, be safer to rely upon an estimation of the oxygen absorbed if that could be done rapidly. We have, therefore, conducted a series of experiments to determine the ratio between the oxygen absorbed in three hours at 27° C., and the amount absorbed in five minutes at the same temperature. From the daily examination of samples from two rivers we obtained the following ratios :—

From River Chelmer, 5 minutes : 3 hours. . . . 1 : 2.1

" " Blackwater, 5 minutes : 3 hours . . . 1 : 2.4

Fully treated waters from above, 5 minutes : 3 hours. 1 : 2.2.

Houston (Annual Report M.W.B. 1923—24) made similar experiments with river waters, and obtained a rather higher ratio.

River Thames, Lee and New River water . . . 1 : 2.39

" " " " " filtered . . . 1 : 2.43

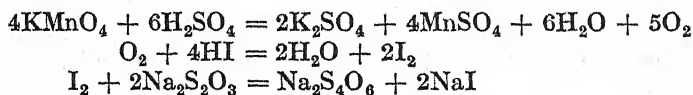
In order to compare results obtained in other laboratories, he found that the oxygen absorbed in three hours at 27° C., if multiplied by 1.05, gives very approximately the amount absorbed in four hours at the same temperature. To compare results obtained in three hours at

27° C. with the results obtained in the same period at 37° C. we made a series of experiments with samples and obtained the following ratios :—

	Oxygen absorbed in 3 hours. at 27° C. at 37° C.		Ratio.	Albuminoid Ammonia.	Ratio of Oxygen absorbed. in 3 hours to the Alb. Ammonia.
Potable waters	0.105	0.119	1 : 1.13	0.011	9.6 : 1
River waters	0.273	0.31	1 : 1.14	0.026	10.5 : 1
Sewage effluents	1.15	1.20	1 : 1.04	0.114	10.1 : 1

The ratio of oxygen absorbed to the albuminoid ammonia varies much more with potable waters than with river water and sewage effluents, but whenever the ratio differs materially from 10 : 1 the determinations are repeated. The ratio for sewage effluents is so constant for domestic sewage that when the difference is marked inquiries are made, and it is usually found that the effluent contains some trade waste, such as tannery refuse or gas liquor.

The reactions which take place in these various processes for estimating the oxygen absorbed may be represented by the following equations :—



Special precautions are necessary when determining the oxygen absorbed by sea-water or waters with high salinity. In the presence of sulphuric acid, the sodium chloride of such waters yields hydrochloric acid which, in the presence of potassium permanganate, liberates chlorine. To prevent the error resulting from loss of chlorine when the bottle is opened, a sealed glass ampoule containing 2 c.c. of a 10 per cent. solution of potassium iodide is enclosed in the stoppered bottle containing the water and reagents. At the completion of the four hours' incubation the ampoule is fractured by a sharp shake of the closed bottle and the chlorine present liberates an equivalent amount of iodine from the potassium iodide. Since the chlorine has been liberated by an equivalent amount of permanganate, the iodine titrated corresponds with that permanganate which would be left after normal oxygen absorption.

Owing to the reaction described above it is necessary to take the further precaution of having a larger excess of permanganate present than would otherwise be the case. An organically pure sea-water requires, for example, 30 c.c. of N/80 potassium permanganate in the oxygen absorbed determination.

Detection and Estimation of Iron

Water containing even a small trace of iron usually becomes opalescent upon exposure to air. This is apparently due to the

absorption of oxygen and the formation of insoluble basic salts from the soluble bicarbonate. If it is desired merely to ascertain the presence or absence of a minute trace of iron, proceed as follows :—

To 50 c.c. of the water, previously agitated, add 1 c.c. of dilute sulphuric acid (1 in 4) and, drop by drop, a solution of potassium permanganate (1 c.c. = 0.1 mg. O), until the faintest possible red tinge is discernible and persists for some minutes. If the water is turbid, the application of heat may be necessary to ensure the solution of the iron and its conversion to the ferric state; filtration through paper removes the last trace of permanganate. Now add 1 c.c. of the solution of potassium ferrocyanide, when a blue tint will be produced if more than 1 part of iron is present in 10 million parts of water, corresponding to 0.01 part per 100,000. The amount of iron present may be estimated by making a solution which gives a colour of equal intensity with the ferrocyanide solution. For this purpose the standard solution of iron, each c.c. of which corresponds to 0.1 mg. of Fe, may be used. Standards are made with known quantities diluted with distilled water to 50 c.c. To each 50 c.c. 1 c.c. of dilute sulphuric acid and 1 c.c. of the ferrocyanide solution are added. If necessary, the process must be repeated until the standard solution and the water have the same tint. If the difference is but slight, the exact amount may be determined by varying the lengths of the columns and making the necessary calculation. If the water gives a dark colour with the ferrocyanide, it should be diluted with a definite quantity of distilled water until the tint produced can readily be matched.

The following table shows that the results are sufficiently accurate for most practical purposes :—

Amount of iron in 100 c.c.		Amount found	Amount of iron in 100 c.c.		Amount found.
0.032 mg.	.	0.032 mg.	0.09 mg.	.	0.08 mg.
0.041 „	.	0.038 „	0.20 „	.	0.20 „
0.041 „	.	0.040 „			

If the water has been heated to effect solution, it must be allowed to become quite cold before the quantitative tests are applied.

The ferrocyanide solution should not have been kept any length of time. A freshly prepared solution is preferable.

The thiocyanate test is sometimes preferred, and is applied as follows :—

Place 100 c.c. of the water in a beaker and add 0.5 c.c. of fuming nitric acid. Warm to about 80° C. and maintain at this temperature for three minutes. Then transfer to a cylinder, cool, and add 2 c.c. of a 10 per cent solution of potassium thiocyanate. If 0.01 part per 100,000 of iron is present, a red colour will be produced. The amount can be ascertained by making standard solutions for comparison.

If exceedingly minute traces of iron are to be estimated, the water may be evaporated down to a fractional part before applying the reagents.

In some cases both the iron in solution and that in suspension require determination. For this purpose the metal is estimated in an unfiltered and a filtered sample, and the difference gives the amount in suspension. It should be remembered, however, that many samples of water which are quite turbid when received for analysis were perfectly clear and bright when collected. The basic salts deposit after the water comes in contact with air, hence the amount of iron in suspension will depend upon the extent of the exposure.

Detection and Estimation of Manganese

The manganese present in a water may be either in suspension or solution, and may exist in different states of oxidation, as manganous or manganic salts or oxides. The manganic salts liberate iodine from potassium iodide in acid solution even when there is only 0.01 part per 100,000 of manganese present in the water. If starch is present, a blue colour appears, and remains fairly constant, whilst the colour produced by nitrites deepens.

If the Griess-Ilosvay test shows the absence of nitrites and only traces of iron are present, the following "presumptive" test for the presence of manganese may be applied :—

To about 50 c.c. of the water add sufficient solution of pure sodium hydroxide to render it distinctly alkaline, and shake it occasionally for about an hour. Then acidify with dilute hydrochloric acid and add a little potassium iodide and starch solution. If a blue colour develops, manganese is probably present. With 0.01 part per 100,000 of manganese the colour is just perceptible; with 0.025 part per 100,000 it is distinct almost as soon as the acid is added. The depth of the colour produced gives a rough idea of the amount present, and the information is useful for the following confirmatory test. If the water contains an appreciable amount of organic matter, the delicacy of the "presumptive" test is impaired.

Minute traces of manganese can be detected, and a close approximation of the amount present made, by the following simple method :—

To 100 c.c. of the water add 1 c.c. of strong nitric acid and a dilute solution of silver nitrate in slight excess of that required to precipitate the chlorides. Raise to boiling point and filter. To the filtrate add 2 grammes of potassium persulphate and boil for ten minutes. A pink colour of permanganate is produced if manganese is present, and its amount can be ascertained by comparison with a solution made by diluting N/80 permanganate. Filtration can be omitted when the salinity of the water does not exceed 8–10 parts per 100,000 as chlorine in chlorides since the silver chloride readily dissolves on adding potassium persulphate, and boiling.

If a water residue is mixed with a little sodium carbonate and potassium nitrate, and heated to fusion, the presence of manganese will be shown by the production of a green colour. This reaction,

however, does not appear to be as delicate as the tests given above. It is useful on occasions as a confirmatory test if there is an appreciable amount of manganese present.

Very often a water, which unfiltered gives the "presumptive" reaction for nitrites with the iodide test, gives no such reaction after filtration. In these cases, the reaction is due to chlorine or manganese which are removed by the filter paper, and not to a nitrite, since the latter would persist in the filtrate.

Detection and Estimation of Zinc

The test applied for the detection of iron will almost certainly have given indications of the presence of zinc, if any compound of this metal is present, by the appearance of an opalescence due to the formation of the very insoluble zinc ferrocyanide. The test can be repeated omitting the addition of the potassium permanganate. With 0.05 part per 100,000 of zinc a decided opalescence will appear in a few minutes; with 0.1 part per 100,000 the turbidity is obvious in about one minute, whilst with 1 part per 100,000 the turbidity appears in a few seconds. The amount of zinc present can be estimated by adding successively to 50 c.c. of the water, 1 c.c. of dilute sulphuric acid and 1 c.c. of solution of potassium ferrocyanide, and placing in the dark. The opalescence produced is then imitated by adding the same quantities of reagents to water to which known quantities of solution of zinc sulphate (1 c.c. = 0.1 mg. Zn) have been added. The turbidity reaches its maximum in about five minutes, unless the zinc is present only in exceedingly minute trace. Slight variations in the quantity of acid or ferrocyanide solution do not appear to affect the results, but the nature and quantity of the acid are not without effect if a marked excess is employed, and the experiment should, therefore, be conducted as described. The reaction will detect 0.05 part per 100,000 of zinc in water, even in the presence of a trace of iron. When the amount present exceeds 1 part per 100,000, it is advisable to dilute the water before estimating the zinc. The following table shows that the results obtained are sufficiently reliable:—

PARTS PER 100,000			
Zinc present.	Zinc estimated.	Zinc present.	Zinc estimated.
0.09 . . .	0.10	0.50 . . .	0.50
0.10 . . .	0.08	0.56 . . .	0.50
0.21 . . .	0.20	0.70 . . .	0.75
0.25 . . .	0.28		

The following confirmatory test is often useful, but, if only very minute quantities of zinc are present, concentration by evaporation is necessary:—

To each of two 100 c.c. samples of the water add 1 c.c. of 10 per cent. hydrochloric acid and 1 c.c. of freshly prepared saturated H_2S solution. Then to one add immediately 5 c.c. of a 10 per cent. solution of sodium acetate, and allow to stand.

With 1 part of zinc per 100,000 a turbidity appears at once in the solution containing the acetate.

With 0.5 part of zinc per 100,000 a turbidity appears in about thirty seconds.

With 0.2 part of zinc per 100,000 a turbidity appears in one minute.

If the solution to which no acetate has been added becomes turbid, the test is useless, since ferric salts are present and sulphur is being deposited.

The presence of any appreciable quantity of zinc is also indicated when the water is being boiled or evaporated. Opalescence is usually observed before ebullition commences, and when the water is being evaporated a characteristic film appears on its surface.

Detection and Estimation of Copper

This metal may be detected by the ferrocyanide test. The copper ferrocyanide produced imparts a reddish-brown tint to the water, and the amount of the metal present can be approximately estimated by comparing the tint produced with that formed in solutions of known strength. Using 50 c.c. of water in an ordinary Nessler cylinder, this test will detect 0.025 part per 100,000 of copper. The ferrocyanide solution (1 per cent.) should be freshly prepared, and the water should be slightly acidulated with dilute hydrochloric or sulphuric acid.

The presence of iron and lead interferes with this reaction. If iron is present and lead absent, the copper may be estimated by the addition of H_2S to an acid solution in the manner described in the next section, using a standard solution of a copper salt in place of that of lead.

Copper sulphide is soluble in potassium cyanide, lead sulphide is not; hence if H_2S gives a coloration with the acidulated water, but no coloration if KCN has previously been added, the presence of copper is confirmed.

Kastle-Meyers reagent was introduced for the detection of minute traces of copper, but its use has not proved satisfactory, and the same applies to sodium ethylxanthate.

The use of sodium diethyldithiocarbamate was suggested by Callan and Henderson (*Analyst*, 1929, 54, 650), who were of the opinion that it was superior to other reagents.

A suitable volume of the water to be tested is rendered alkaline with ammonia, 10 c.c. of a 0.1 per cent. aqueous solution of the reagent added, and the volume made up to 100 c.c. in a Nessler cylinder. In the presence of copper a golden-brown colour develops and this can be detected with as little as 0.001 part per 100,000 of copper. The amount of copper in the water to be tested should not exceed 0.1 mg. per 100 c.c., since the depth of colour becomes too dark for satisfactory matching.

The amount of copper is estimated by comparison with dilutions of a standard copper sulphate solution containing 0.01 mg. of copper per 1 c.c. The stock standard solution (10 times strength) is prepared

by dissolving 0.3928 gram pure recrystallised copper sulphate in 1 litre of water (1 c.c. = 0.1 mg. Cu.).

The test is affected by the presence of iron, lead and zinc, and means to overcome this difficulty have been devised by Haddock and Evers (*Analyst*, 1932, 57, 495). The process consists in the addition to the water to be tested of 2 grams of citric acid, followed by ammonia till the reaction is pH 9 or over, and the sodium diethyldithiocarbamate is then added. The colour formed can be extracted by carbon tetrachloride.

Sodium diethyldithiocarbamate is a more delicate reagent for copper than is potassium ferrocyanide.

Another colorimetric method for the detection and estimation of copper consists in the use of dithio-oxamide (rubeanic acid) as the colour-forming reagent. To 90 c.c. of the water under examination, the following reagents are added in succession:—2 c.c. of glacial acetic acid, 6 c.c. of 5N ammonium acetate, 1 c.c. of 0.1 per cent. alcoholic solution of rubeanic acid. The olive green colour which forms when copper is present is matched against standard copper solutions treated in a similar manner. This test is as simple as that using dithiocarbamate, but is not quite as sensitive. Larger amounts of copper can, however, be estimated directly over a range of 0.1 to 0.8 part per 100,000, and traces down to 0.01 part per 100,000 can be detected.

Detection and Estimation of Lead

Before testing for this metal, an examination for iron and copper must have been made, since the presence of these metals prevents any accurate estimation of the amount of lead present, or may cause its presence to be entirely overlooked. If these impurities are absent, and the water is practically free from colour, proceed in the following manner¹:—

Take 100 c.c. in a Nessler glass which has been thoroughly cleaned with dilute hydrochloric acid and rinsed with tap water, and add about 3 c.c. of the acetic acid gelatin solution (*vide* Appendix) and 5 c.c. of freshly prepared H₂S solution.

If lead is present, the colloid sulphide formed will have an orange-yellow colour, and will appear immediately. The smallest quantity definitely detectable is 0.01 part per 100,000. With 0.1 part per 100,000 the colour is very distinct.

Now prepare a solution by diluting the standard lead solution which contains 0.1 mg. of lead per c.c., and add the reagents as above. If the colours produced are approximately of the same depth, they can be Nesslerised in the usual way. The colour of the liquid remains unchanged for hours.

The effect of copper and iron is shown in the following table. The colour produced in the presence of these metals is a curious pale yellow

¹ For an alternative method, using diphenyl thiocarbazonone in carbon tetrachloride, see Tompsett, *Analyst*, 1936, 61, 591.

with no orange tint. The water used in the experiments from which this table was made contained 0.2 mg. lead in 100 c.c. :—

Copper added per 100 c.c.	Lead found.	Iron added per 100 c.c.	Lead found.
0.1 . . .	0.1	0.1 . . .	0.06
0.05 . . .	0.06	0.05 . . .	0.06
0.025 . . .	0.06	0.02 . . .	0.07
0.01 . . .	0.09	0.01 . . .	0.14
0.005 . . .	0.12	0.005 . . .	0.2
0.0025 . . .	0.16		
0.001 . . .	0.19		

Filter papers of commerce which have not been acid-exhausted may contain sufficient iron to affect the reaction, but, more serious still, they may contain lead in appreciable quantity, and even copper has been detected in the ash. The water examined must not therefore have been passed through such a paper (*Analyst*, March, 1924).

Water containing lead in solution, and having an alkaline reaction (pH 7.5 or over), has the lead partly or entirely removed upon filtration through paper, asbestos, or a Berkefeld or Pasteur filter. If rendered distinctly acid with acetic acid, such a solution can be passed through any of these filters without loss of lead.

If the water to be examined contains copper, iron, or colouring matter, add to some distilled water the requisite amount of copper or iron and dilute solution of burnt sugar, to make a standard water corresponding in colour, etc., to the water to be examined. This can then be used for making the standard lead solutions.

When it is known that the water has taken up the lead from service pipes through which it has passed, it is better to obtain some of the water from its source, or from some point where it has not been in contact with lead. This water can then be utilised for making the standard solutions.

When the amount of lead present exceeds 0.4 part per 100,000, the water should be suitably diluted, as the most reliable results are obtained with solutions about this strength or below. With quantities of 0.05 part per 100,000 or less, the standard should be made to correspond closely.

As a confirmatory test for lead, concentrate to a few c.c. 100 c.c. or more of the sample acidified with acetic acid. Filter through a small lead-free filter paper into a 15-c.c. centrifuge tube and wash the filter paper with hot acetic acid. Add a crystal of potassium chromate to the filtrate, and stand it in boiling water for five minutes. Cool and centrifuge. If lead is present in solution, lead chromate is formed. To estimate the amount, wash the deposit till free from soluble chromate, dissolve in dilute HCl., transfer to a beaker, add potassium iodide, and titrate the liberated iodine with N/200 thio-sulphate solution (1 c.c. = 0.343 mg. Pb.).

When a water has passed through a lead pipe and has then stood some time in a glass bottle, lead is occluded to, or adsorbed on, the glass surface. After removing a small portion to determine the pH,

a little acetic acid should be added to the water in the bottle, and the mixture well shaken for a few seconds. The water can then be used for the lead estimation.

Detection and Estimation of Arsenic

It is rarely necessary to examine water for arsenic, but we occasionally have to do so, and the tests commonly used for this metal, such as Marsh's and Gutzeit's, can be applied to water. A litre of the water is acidified with hydrochloric acid and concentrated by evaporation to 50 c.c. Marsh's test is then applied and the amount of arsenic present estimated by comparison with standard "mirrors."

Detection and Estimation of Aluminium

Either of the following processes can be used :—

1. *Hæmatoxylin Test* (*Analyst*, 1924, 49, 243).¹ Take 50 c.c. of the water in a Nessler cylinder and add 1 c.c. of ammonium carbonate solution (to adjust pH to 8.2) and 1 c.c. of a 0.1 per cent. solution of hæmatoxylin. Allow to stand ten minutes, then acidify with 1 c.c. of 30 per cent. acetic acid. The colour thus obtained can be compared with standards prepared with known amounts of aluminium and treated in a similar manner.

2. *Aurintricarboxylic Acid Test* (*Analyst*, 1929, 54, 680). The solutions required are: (1) 0.1 per cent. aurintricarboxylic acid; (2) 5N ammonium acetate; (3) 1.5N hydrochloric acid; (4) 5N ammonium chloride; (5) 3.2N ammonium carbonate.

A volume of the water, 100 c.c. or more, according to the amount of aluminium present, is made acid and evaporated to 20 c.c. Then add 5 c.c. of the ammonium acetate solution, 5 c.c. of the hydrochloric acid, and 2 c.c. of the aurintricarboxylic acid. Place on a water-bath at 80° C. for ten minutes. Add 5 c.c. of the ammonium chloride solution, cool and add 5 c.c. of the ammonium carbonate solution with gentle shaking. Make up to 50 c.c. with distilled water and mix. The pH should be 7.1 to 7.3. A red colour present in the blank control should disappear in about fifteen minutes. Allow to stand twenty minutes when the excess dye becomes decolorised, and then compare the colour with those obtained in similarly and simultaneously treated standards containing known amounts of aluminium, such as 0.01, 0.03, 0.05 mg., etc.

Detection and Estimation of Sulphuretted Hydrogen

The most delicate test for the presence of this gas is given by its odour. When this is pronounced, the addition of a little acid and a few drops of lead acetate solution (*vide* Appendix) may produce a marked discoloration. Some waters have a decidedly suggestive smell

¹ Critical reviews of this method have been made, and modifications described, by G. U. Houghton, 1943, *Analyst*, 68, 808, and N. Strafford and P. F. Wyatt, 1943, *Ibid.*, 68, 812.

of this gas, but do not give a positive reaction with lead acetate. In one such case the first portion of the distillate from the acidified water gave a decided reaction when a lead salt was added. The hydrogen sulphide somewhat rapidly absorbs oxygen, with liberation of sulphur and disappearance of the odour. This change probably takes place in stages, sulphur compounds, sulphites, thiosulphates, etc., being formed which possess the power of decolorising iodine. The following quantitative test gives the total iodine absorbed, and for practical purposes may be expressed in terms of H_2S .

Very faintly acidulate 500 c.c. of the water with dilute sulphuric acid, add a little solution of starch, and run in a centinormal solution of iodine until a blue tint appears. A little of the water is then added from a graduated tube until the colour disappears. The iodine used corresponds to the H_2S , etc., present in 500 c.c. plus half the amount required to decolorise the iodide of starch.

The following is an example of such a determination. The water was derived from the boulder clay in the north-west of Essex, and had a strong odour of sulphuretted hydrogen.

To produce a blue tint with 500 c.c. of the water, to which 5 c.c. of starch solution had been added, 9 c.c. of centinormal solution of iodine were required. The addition afterwards of 8 c.c. of the water decolorised the solution.

The reaction being $\text{I}_2 + \text{H}_2\text{S} = 2\text{HI} + \text{S}$, 1 c.c. of the iodine solution was equivalent to 0.17 mg. of H_2S , and $500 + \frac{8}{2}$ c.c. contained 9×0.17 mg. of $\text{H}_2\text{S} = 3.1$ mg. per litre or 0.31 part per 100,000.¹

Alkaline sulphur waters which have undergone change by exposure to the air may be evaporated to dryness after the addition of a little sodium hydroxide and potassium nitrate, then gently ignited, and the SO_4 in the residue determined. The difference between the sulphates in the original water and in the ignited residue is due to the sulphur existing in other forms of combination.

In a water polluted with soakage from a gasworks, it was found that a considerable amount of iodine was decolorised by the contaminated water, whereas the unpolluted water absorbed practically no iodine. The ammonia and the total sulphates were also higher in the polluted water.

¹ For an alternative method of estimating sulphide and sulphuretted hydrogen in concentrations of less than 1.0 part per million, see Pomeroy, *Jour. Amer. Water Wks. Assoc.*, 1941, 33, 943.

CHAPTER XIX

EXAMINATION OF GROSSLY POLLUTED WATERS, SUCH AS SEWAGE AND SEWAGE EFFLUENTS

In the investigation of rivers and streams, samples of water should be taken from every tributary, stream, ditch or pipe discharging therein.

If the discharge is from a factory or works of any kind, special examinations may have to be made according to the nature of the working processes employed. The Royal Commission on the Treatment and Disposal of Sewage dealt with the effluents from the principal manufacturing processes, and the Ninth Report, Vol. I. especially, should be consulted in this connection. A Committee was later appointed by the Minister of Health to consider various points arising from the Reports of the Royal Commission, particularly with regard to the standardisation of methods of analysis, and the Report of this Committee, entitled "Methods of Chemical Analysis as applied to Sewage Effluents," issued by the Ministry of Health in 1929 and reprinted in 1934, should be consulted by all interested in this subject.

Sewage effluents and trade wastes usually contain matter in suspension, and it is often very troublesome to obtain for analysis a small sample which truly represents the bulk, but this must be done so far as possible. A composite sample (called an average sample), made up by bulking twenty-four samples, collected one at each hour of the day, and mixed in proportions according to the hourly flows as ascertained by careful gaugings, is often the best and only means of obtaining a representative sample.

The importance of careful and representative sampling, maintaining so far as is possible the true proportion of suspended matter to liquid, cannot be overrated, but is frequently ignored. The scraping into the bottle of solid matter accumulated at outfalls, or the stirring up of the river bed, is a not infrequent practice, and gives an entirely false sample.

Wide-necked, glass-stoppered bottles of half-Winchester size are suitable for such samples. The samples should be delivered to the laboratory as soon as possible, and the analysis commenced within twenty-four hours of collection. If this is impossible, the sample should be kept in a refrigerator.

Effluents from some factories are hot on discharge into a river, and, in such cases, the temperature should be taken on collection of the samples.

The examinations of samples of sewage effluents, etc., are undertaken in most cases to determine :—

1. The efficiency of processes of purification.

2. The extent of the injurious effect, if any, on the river waters into which they are discharged.

In the former case, corresponding samples of the raw sewage or trade-waste will also be required for examination, and in the latter case, samples of the river water above and below the outfall should also be collected. The sample of river water below the outfall should be at such a distance that complete admixture of effluent and river water has occurred. In inland rivers and streams a distance of 100 yards usually suffices.

Sewage effluents, etc., are usually examined to determine :—

1. The physical characters, such as turbidity, colour and odour.
2. The reaction or *pH*.
3. The total matter in suspension.
4. The character of the suspended matter ; the presence of fungus or other growths.
5. The chlorine in chlorides.
6. The nitrogen in nitrites and nitrates.
7. The free ammonia.
8. The albuminoid ammonia.
9. The oxygen absorbed from permanganate.
10. The dissolved oxygen absorbed (Biological Oxygen Demand).
11. The presence of free chlorine or other bactericidal agent.
12. The stability or keeping quality.

Occasionally the total solids in solution are determined, and also the organic portion of the matter in suspension. Tests may also be made for thiocyanates and phenols, especially if the presence of gas-works waste is suspected. Other determinations which are sometimes required in crude-sewage analysis, particularly in connection with purification by the activated sludge process, are the "Settleable Solids," and the alkalinity. The former is a measure of the volume of the sludge which settles under certain standard conditions.

The analysis should be carried out on the liquid plus its suspended matter, that is, the sample should be well shaken before each portion is withdrawn for the various determinations.

The physical characters should first be noted.

Colour. Satisfactory sewage effluents generally have only a slight yellow colour, and the presence of distinct colour should be recorded. Such may be due to the presence of trade-waste, or growth such as protococci or other chlorophyll-containing organisms. Suitable tests, or microscopic examination, should be made to ascertain the cause of abnormal discoloration.

Odour. This should be observed as soon as the bottle is opened. Trade-wastes often have distinctive odours, but sewage effluents should either be odourless, or have only an earthy odour. An odour of urine, sewage or sulphuretted hydrogen indicates an unsatisfactory condition.

Reaction. The reaction and *pH* can be ascertained by the use of indicator solutions as described in the case of potable waters. Sewages

and sewage effluents are generally neutral or faintly alkaline in reaction, but trade-wastes are often acid. Undue alkalinity or acidity should be determined and recorded.

Alkalinity and Acidity. These are determined in the usual manner, and the results expressed in terms of sulphuric acid. Owing to the difficulty of deciding the end-point when discoloured or turbid effluents and trade-wastes are titrated, it is better in such cases to take 250 c.c. to 500 c.c. of the sample instead of 100 c.c. and titrate with N/1 instead of N/10 sulphuric acid or soda. Also, we find the use of benzene-azo- α -naphthylamine as indicator is preferable to methyl orange.

These determinations are required only when excessive alkalinity or acidity has been indicated by the pH tests, and the results obtained by the above methods are sufficiently accurate, as a rule, for all practical purposes.

Suspended Matter. 1. A fairly uniform mixture having been obtained, 25 to 200 c.c., depending on the amount of suspended matter present, are passed through a tared Gooch filter prepared with a layer of floss asbestos, the deposit washed with a little distilled water, and the filter dried at 100° C. to 105° C., and weighed.

A constant weight having been obtained, the crucible may be ignited and the loss on ignition ascertained. An attempt has been made to convert this loss into an estimate of the organic matter present by recarbonating. The recarbonated residue is then regarded as the inorganic matter, and the difference between this and the total solids as being organic matter. The determination of the latter may on occasions be useful, but it can make no pretence to accuracy. The total solids may be determined from the evaporation of 100 c.c. of the crude liquid, and, in order to estimate the organic portion, incinerate and recarbonate the residue, and by difference obtain the loss. If nitrates are present, these may be estimated, and the oxygen lost by ignition calculated and added to the weight of the carbonated residue. These results are usually recorded in the following way:—

- (a) Total matter in solution and suspension.
 - (b) Organic matter in solution and suspension.
 - (c) Total matter in suspension.
 - (d) Organic matter in suspension.
- Thus (a) — (c) gives (e), total matter in solution.
(b) — (d) gives (f), organic matter in solution.

2. The centrifuge method of estimating the suspended matter is sometimes used as an alternative to the Gooch crucible method, but it is less satisfactory.

A volume of the sample, according to its suspended matter, is centrifuged in a tube until the solids are collected at the bottom. The top liquid is then poured off, the deposit washed with distilled water, and then transferred by means of a little distilled water into a crucible. The water is then evaporated, the crucible dried at 100° C. to 105° C., and weighed.

The readings are usually lower than with the Gooch crucible method.

The careful estimation of the solids in suspension is important, since the fitness or otherwise of an effluent for discharge into a river is partly based on this determination.

The appearance of the suspended matter should also be noted, and when the amount is excessive, or its character abnormal, special examinations should be made to ascertain its composition. The total solids in solution are sometimes excessive in trade-wastes, and, in such cases, analysis of the saline constituents may be required.

Settleable Solids. The determination of "settleable" solids of sewage gives a measure of the volume of suspended matter which will settle under standard laboratory conditions. The procedure recommended in the U.S.A.¹ is as follows :—

"Fill an Imhoff cone to the litre mark with a thoroughly mixed sample. Settle for 1.75 hours, gently stir the sides of the cone with a rod or by spinning, settle 0.25 hours longer and record the ml. of 'settleable' solids in the cone. In hot weather it may be necessary to reduce the settling to 1 hour because of floating sludge. Some operators prefer to use the theoretical detention period of the plant settling units."

These settled solids can be removed and the weight determined, if required.

The "sludge index" is the volume in ml. occupied by 1 gm. of sludge and it refers particularly to activated sludge.

Chlorides. A number of interfering factors may render this estimation difficult. The usual titration with silver nitrate solution can be employed, provided the pH lies between 6 and 8, the liquid is clear and not highly coloured, and the content of free ammonia or sulphides is not abnormally high. Excessive turbidity, colour, free ammonia or sulphide can often be dealt with by treating the sample with 0.1 to 0.2 gm. of zinc sulphate, followed by a few drops of 10 per cent. sodium hydroxide and filtration prior to silver nitrate titration. The presence of thiocyanates, thiosulphates, and other sulphur compounds, also cause interference. These may be destroyed by acidifying the sample with sulphuric acid and boiling for a few minutes with a few drops of 10 vol. hydrogen peroxide (free from chlorides). After cooling, and neutralisation with sodium carbonate or calcium carbonate, titration with silver nitrate solution can be carried out.

An alternative method of treatment, particularly useful when dealing with highly-coloured liquids, or effluents containing thiocyanates, thiosulphates, sulphides, etc., is as follows: To an aliquot portion of the sample add 2 c.c. of concentrated nitric acid and evaporate to about half the volume by boiling. Then add precipitated chalk slowly until a slight excess of the solid remains. After cooling, the silver nitrate titration can be carried out in the usual manner.

If interference with the chlorine determination is caused simply by

¹ "Standard Methods for the Examination of Water and Sewage," 8th Edit. American Public Health Association.

acidity, the addition of an excess of solid calcium carbonate provides a convenient method of neutralisation. Should these methods fail, the sample should be evaporated to dryness, and the chloride determined in the carbonised residue.

The chlorides in sewage include the chlorides in the water supply, which may vary from 1.0 to 70 parts per 100,000, the chlorides added from base-exchange softening-plants and other household and industrial processes, in addition to the chlorides derived from excreta, chiefly t urine. The chlorine in chlorides determination is, therefore, often of little value in considering the "strength" of sewage.

The chlorine estimation may be valuable in comparing the sewage and sewage effluents from the same works, but it is useless for comparing sewage or sewage effluents from different localities.

The Nitrogen in Nitrites and Nitrates. The presence of nitrites is usually determined by the Griess-Ilosvay test, and the nitrous and nitric nitrogen by the CuZn couple method, using a portion of the sample, which, after the addition of a few drops of 10 per cent. sodium hydroxide solution, has been boiled in order to drive off the free ammonia. We regard this as a reliable method of estimating the nitrates in the presence of organic matter, the results being sufficiently accurate for practical purposes, and the process is simple and convenient.

The presence of nitrites in a sewage effluent indicates that the process of purification is proceeding, since they are oxidation products intermediate between ammonia and nitrates.

The more efficient the process of sewage purification the less is the amount of nitrogen as free ammonia, and the greater the amount of nitrogen as nitrites and nitrates.

Free Ammonia. An aliquot portion, up to 100 c.c., of the uniform mixture is added to 500 c.c. of ammonia-free distilled water, and the whole rendered faintly alkaline by the addition of a few drops of a 10 per cent. solution of sodium carbonate or hydroxide. In the manner described in Chapter XVIII., 200 c.c. are distilled, the distillate being collected in a flask containing a few cubic centimetres of acidulated water. An aliquot portion is taken for Nesslerisation. A further 50 c.c. is distilled and Nesslerised to make certain that all the ammonia has been collected.

In the case of crude sewages, tank liquors, or other grossly impure fluids, the initial quantity taken for distillation should be less, such as 1 c.c. or 2 c.c. to 10 c.c. This should be obtained by first making a 1 in 10 dilution of the sample (50 c.c. to 450 c.c. of ammonia-free water) and pipetting the appropriate amount from this dilution. Unless this dilution method is employed, error will arise, for it is impossible to pipette directly 1 c.c. which is truly representative of the sample in the case of impure liquors containing much suspended matter.

Albuminoid Ammonia. To the remaining 250 c.c. of water in the flask 50 c.c. of alkaline permanganate are added, and the distillation is continued in the usual way. Collect 200 c.c. and Nesslerise an aliquot part. On occasions, the whole of the ammonia obtainable is not col-

lected, but the results are sufficiently reliable and useful for all practical purposes.

In respect of sewage effluents which are discharged into inland rivers, the albuminoid ammonia should not exceed 0.15 part per 100,000. The figure in really good effluents is under 0.10 part per 100,000. To convert free ammonia and albuminoid ammonia into ammoniacal nitrogen and albuminoid nitrogen respectively, multiply by 14/17 or 0.823.

Oxygen Absorbed from Acid Permanganate. This determination is similar to that employed for potable waters, except that different quantities of the sample, and of the reagents, are taken. In these details, the recommendations contained in the Report issued by the Ministry of Health are now generally followed in this country.

The volume of the sample taken varies from 10 c.c. to 100 c.c., depending on its degree of impurity, 25 per cent. sulphuric acid is used, and the strength of the permanganate solution is N/80. The periods of time for the test are (a) three minutes and (b) four hours, and the temperature is 26.7° C. (80° F.).

Sufficient permanganate should be added to provide a marked excess and to ensure that at the end of four hours about half of the available permanganate oxygen remains unconsumed. An indication of the required amount will be given by the result of the three minutes' test, which is first performed. The addition of 50 c.c. of N/80 permanganate is suggested in the Ministry of Health Report.

The permanganate, and 10 c.c. of acid, are pipetted into a glass-stoppered bottle of 250 c.c. capacity and warmed to 26.7° C. A portion of the sample and distilled water (both warmed to this temperature) are added to make a total volume of 160 c.c. and the whole is maintained at 26.7° C. for four hours. The bottle and controls are then rapidly cooled, potassium iodide added, and the liberated iodine titrated with freshly standardised thiosulphate solution, using a little starch solution towards the end of the reaction.

With very polluted liquors N/8 permanganate is sometimes used, but in this case the fact should be stated on the report. In order to obtain comparable results it is essential to standardise the test in all its details. If N/8 permanganate is used instead of N/80, the oxygen absorbed figure is higher.

Generally speaking, with sewage effluents and river waters, the oxygen absorbed from permanganate is roughly ten times the albuminoid ammonia. This ratio is disturbed by the presence of certain trade-wastes.

The oxygen absorbed from permanganate in four hours at 26.7° C. by a good sewage effluent is under 1.0 part per 100,000, and should not exceed 1.5 parts per 100,000, where the effluent is discharged into an inland stream.

The "Strength" of Sewage. The oxygen absorbed from permanganate in four hours, multiplied by 10, expresses, in the case of sewage and partially purified sewage, the approximate "strength" of

the sewage as calculated from McGowan's formula. This formula, for sewage and septic tank liquors, is as follows :—

$$\text{"Strength"} = 4.5 (A + B) + 6.5 C.$$

Where A = the nitrogen in the free ammonia, parts per 100,000.

B = the nitrogen in the albuminoid ammonia, parts per 100,000.

C = the oxygen absorbed from N/8 permanganate in four hours at 26.7° C., parts per 100,000.

This gives an approximation of the "strength" of a sewage. The "long-aeration" method described in the Eighth Report of the Royal Commission, Vol. II., Appendix, has no application in practice where the figure must be rapidly ascertained.

The "strength" of sewage depends on the amount and the character of the impurities present, and it refers to the amount of oxygen required to oxidise these impurities. The amount of oxygen required for the completion of the process cannot be determined by any practical method. Even when the "long-aeration" method is continued for two or three months, completion is not reached.

McGowan's formulæ, which are based on quickly obtainable analytical results, were therefore devised from numerous experiments for the purpose of providing a rough but ready indication of the "strength" of domestic sewages and tank effluents.

The "strength" figure obtained by McGowan's formulæ is useful in the comparison of different samples of domestic sewages, but it has little other purpose or significance.

Domestic sewages can be classified according to the "strength" figure, or the oxygen absorbed from N/8 permanganate, as follows :—

Domestic Sewage.	Strength Figure McGowan's Formula.	O.A. from N/8 permanganate. Parts per 100,000
Weak	70 to 80	less than 8
Average	100 to 120	10 to 12
Strong	170 to 250	17 to 25
Very strong	250 or more	25 or more

In calculating the "strength" of sewages by McGowan's formulæ it is important to note that the oxygen absorbed figure is obtained with N/8 permanganate. If N/80 permanganate is used, and the technique is otherwise identical, a lower oxygen absorbed figure is obtained. In the Ministry of Health Report on Methods of Sewage Analysis it is suggested that "When N/80 permanganate has been used in the 'oxygen absorbed' test this figure would have to be further multiplied by 1.6 in order to give an approximately correct result." It is not clear how this factor of 1.6 was obtained nor is it established that it is reliable in giving "an approximately correct result."

The "Impurity Figure" of a Sewage Effluent. An opinion as to the

suitability of an effluent must often be given quickly and before the result of the five days' dissolved oxygen absorbed test is available. This, we have found from long experience, can usually be given on three determinations, all of which can be completed in a few hours.

1. The solids in suspension, which should not exceed 3 parts per 100,000.

2. The albuminoid ammonia.

3. The oxygen absorbed from permanganate.

The "impurity figure" or "strength" can be conveniently assessed from determinations (2) and (3) above expressed in parts per 100,000, and is calculated as follows:—

$$\frac{(\text{Albuminoid ammonia} \times 100) + (\text{Oxygen absorbed} \times 10)}{2}$$

It is usually found that if this "impurity figure" is under 10 the effluent is a good one, if under 15 it is passable.

This standard is applicable to inland rivers and streams and is adopted by the Essex County Council. Its wide application has been entirely satisfactory, and it has been found that an effluent which conforms to this standard will not give rise to nuisance in the river, and only occasionally will such an effluent fail to pass the five days' dissolved oxygen absorbed standard of 2 parts per 100,000.

Estimation of Dissolved Oxygen and Oxygen Absorbed from Solution. As it is by dissolved oxygen that the natural purification of a river is effected, polluting organic matter being oxidised to innocuous substances, the degree of oxidation is a most useful measure of river water purity. Representative samples, such as at mean depth in mid-stream, should be collected, and as the sample can be used for this determination only, a separate larger sample should be taken at the same time if a general analysis of the river water is also required.

A convenient method of sampling is to attach to the end of the same rod:—

1. A wide-mouthed bottle of about 1 litre capacity.

2. A displacement sampling apparatus, such as Casella's,¹ containing the bottle for the sample intended for the dissolved oxygen determination.

(3) A thermometer in a protecting metal cup.

In this way the two samples, and the temperature at the time of sampling, can be obtained in one operation.

The sample bottles for the displacement apparatus are of about 300 c.c. capacity, with well-fitting stoppers which can be inserted into the full bottle without including an air bubble. A stock of these bottles should be prepared having the stoppers numbered to correspond with the bottles, and the exact capacity—full with stopper inserted—marked on the glass by a diamond. It is advisable also to have these bottles

¹ Manufactured by Messrs. C. F. Casella & Co. Ltd., Regent House, Fitzroy Square, London, W.1.

plainly marked with a serial number cut in the glass, since adhesive labels will not survive the subsequent operations.

Determination of Dissolved Oxygen. The method recommended is that of Winkler, and it depends on the oxidation of manganous hydroxide by the oxygen in solution, and the subsequent titration of an equivalent amount of iodine set free from potassium iodide. Sewage effluents and polluted waters may contain nitrites which, by liberating iodine from potassium iodide, interfere with the final titration. In such cases it is necessary to treat the sample with a slight excess of potassium permanganate in acid solution before determining the dissolved oxygen.

This modification, first suggested by Rideal and Stewart, although not recommended for river waters by the Rivers Pollution Committee of the Ministry of Agriculture, entails but little extra work and may be used with advantage in all cases. The process thus becomes divided into three stages :—

1. Preliminary oxidation.
2. Fixation of the dissolved oxygen.
3. Measurement of the dissolved oxygen by liberation of iodine and titration with thiosulphate solution.

The first and second stages should be carried out within half an hour of sampling, and the third stage can be left until the sample is returned to the laboratory.

1. *Preliminary Oxidation.* The sample having been taken, the stopper is inserted whilst the bottle is still submerged in the Casella apparatus. The full bottle is then removed from the apparatus, the stopper taken out, and 1 c.c. of concentrated sulphuric acid added by pipette, followed by sufficient $\frac{N}{8}$ potassium permanganate to leave a slight excess of the latter after the sample (stoppered without air bubble) has stood for fifteen minutes. One cubic centimetre of the permanganate is usually sufficient.

When a slight excess has been maintained for fifteen minutes, as shown by a faint pink colour remaining, this excess is destroyed by the addition of 1 c.c. of a 2 per cent. potassium oxalate solution, the bottle being carefully re-stoppered as before.

2. *Fixation of the Dissolved Oxygen.* When the liquid has become colourless, 1 c.c. of 30 per cent. manganous sulphate is added by pipette, followed immediately by 3 c.c. of a mixed solution containing 70 per cent. potassium hydroxide and 10 per cent. potassium iodide. The stopper is inserted and tied down, and the sample is packed for carriage to the laboratory, where the final stage, the measurement of the oxygen, is carried out.

3. *Measurement of the Dissolved Oxygen.* Five c.c. of concentrated sulphuric acid are run in from a pipette, the bottle re-stoppered and rotated until the precipitated hydroxides of manganese are dissolved. The iodine which is set free in the acid mixture is then titrated by $\frac{N}{80}$ sodium thiosulphate solution.

This may be carried out in the same bottle by first pipetting out exactly 50 c.c. of the liquid and rejecting ; then running in thiosulphate solution from a burette to the remainder in the bottle until the yellow colour is almost destroyed, and completing the titration after addition of a little freshly prepared starch solution.

The capacity of the bottle being known, the results are calculated on the volume titrated, *i.e.*, volume of bottle less 50 c.c. Alternatively, 250 c.c. of the liquid may be measured out and transferred to a separate flask for titration. One c.c. $\frac{N}{80}$ sodium thiosulphate corresponds to 0.1 mg. oxygen. Therefore, if 250 c.c. of the liquid are used for the titration, the number of c.c. of thio. required, multiplied by $\frac{4}{100}$, gives mg. of oxygen per 100 c.c., or parts per 100,000 by weight.

No correction is made for the volume of the reagents added, as the maximum error from this source is not over 2 per cent. of the oxygen present. In the Ministry of Health Report referred to on p. 257, the procedure described retains the use of manganous chloride solution and hydrochloric acid, but we prefer manganous sulphate solution and sulphuric acid, which reagents are also prescribed by the American Public Health Association in "Standard Methods." If hydrochloric acid is used, care must be taken to exclude the presence of free chlorine which interferes by liberating iodine from potassium iodide. The presence of free chlorine in effluents may also cause interference.

The process is inapplicable to effluents and trade-wastes containing sulphites, thiosulphates, sugars, starches, etc. (substances which are not readily oxidised by permanganate in the cold), and in such cases the alkaline-hypochlorite modification of Theriault is suggested in the American "Standard Methods."

Estimation of the Dissolved Oxygen Absorbed (Biological Oxygen Demand). This is a laboratory method of assessing the degree of pollution of a stream, or the possible effect of polluting matter discharged into a stream, by measuring the loss of oxygen in solution from a closed sample when kept at 18° C. for five days.

Oxygen is absorbed from solution at ordinary temperatures partly by chemical reducing agents, but chiefly by bacterial action. Hence this test has been called the Biological Oxygen Demand of a stream or effluent, and designated the B.O.D.

Water saturated with air at 18° C. will contain a little less than 1 part per 100,000 of oxygen in solution, and as a good effluent will absorb more than this amount in five days, impure river waters and effluents must be diluted with a well-oxygenated water before carrying out this test. It is advisable to arrange the dilution that not more than 50 per cent. of the oxygen present is absorbed at the end of five days. It is advisable therefore to prepare several dilutions for each sample under examination.

Suitable dilutions are generally of the following order :—

River waters, 1 in 3.

Good sewage effluents, 1 in 5.

Poor effluents, 1 in 10.

Tank liquors, etc., 1 in 50, 1 in 100 or 200.

The diluting water should be good, thoroughly oxygenated, tap water, free from traces of copper, zinc, free chlorine or anything likely to inhibit bacterial action, and it should be kept in partly filled Winchester quart bottles at 18° C. for some hours before use.

Sufficient of the dilution should be made in a flask of ample size and, after gentle mixing, the two bottles required for one determination are filled completely, and stoppered without air bubbles. One bottle is placed in the incubator at 18° C. for five days, and in the other, the oxygen in solution is determined at once, as described in previous paragraphs. The preliminary oxidation by sulphuric acid and permanganate should not be omitted.

At the end of five days, the oxygen remaining in solution in the other bottle is determined in the same way, the difference between the two determinations giving the oxygen taken up by the dilution in the interval, and this, multiplied by the dilution factor, gives the oxygen absorbed from solution, or B.O.D., of the effluent or river water. For example :—

A good sewage effluent diluted with four parts of tap water.

Dissolved oxygen in mixture at start	0.90	parts per 100,000.
Dissolved oxygen in mixture at end of five days	0.58	" " "
Oxygen absorbed from solution	0.32	" " "
Oxygen demand of effluent $\therefore = 0.32 \times 5 =$	1.60	" " "

The "dissolved oxygen absorbed in five days" test (Biological Oxygen Demand) is valuable in assessing the efficiency of sewage purification works, the probable effect of effluents on river waters, and the purity of river waters.

In its application to crude sewage and trade-wastes, certain precautions are necessary in order to avoid fallacious results. For example, some trade-wastes, even after dilution as required in the test, retain sufficient concentration of free chlorine, or other antiseptic, to inhibit the biological processes involved in the test, and thereby vitiate the results. In such instances, it is necessary to seed the sample with bacteria, after neutralising the interfering substances, the presence of which has been ascertained by preliminary examinations.

The presence at the point of discharge to a stream of appreciable concentrations of free chlorine, or other antiseptic, in an effluent of bad quality, may temporarily arrest putrefaction and thus delay absorption of oxygen. After dilution with river water, however, the inhibition of biological activity may be removed, when, unless the dilution is very great, putrefaction will occur with all its associated signs of pollution.

A river water may, therefore, present a satisfactory condition for a short distance below such an outfall, yet show, at some greater distance downstream, complete depletion of oxygen with its accompanying

effects of blackening, offensive odour, fungus growth, fish destruction, etc.

The Royal Commission based most of their conclusions upon the results of the dissolved oxygen absorbed test. They showed that a good sewage-purification process produced an effluent which, under the conditions of the test, will not take up more than 2 parts of dissolved oxygen per 100,000, and they based their conclusions upon what an effluent should be by the effect it would produce in the stream into which it is discharged, that effect being again measured by the same test, and in no case should the affected river water absorb more than 0.4 part per 100,000 of oxygen in five days (*vide* Table, p. 271).

The condition of rivers was also judged by the amount of oxygen the water absorbed in five days, and the rivers were classified as under:—

	Water not absorbing more than
Very clean rivers	0.1 part per 100,000 in 5 days.
Clean rivers	0.2 " " " "
Fairly clean rivers	0.3 " " " "
Rivers of doubtful purity	0.5 " " " "
Bad or polluted rivers	1.0 " " " "

This process is not always used in sewage-effluent and river-water analysis chiefly because it takes five days for its completion, and engineers and sewage works managers often find it inconvenient to wait six days for the results of an analysis when reliable results are obtainable in much shorter time. Extended experience shows that effluents which do not absorb more than 1 part per 100,000 of oxygen from permanganate in four hours at 26.7° C., and do not yield more than 0.15 part per 100,000 of albuminoid ammonia, almost always absorb less than 2 parts of dissolved oxygen in five days. For this reason the permanganate process, which can be completed in four hours, is not likely to be entirely supplanted by the dissolved oxygen absorbed in five days' test.¹

In examining rivers, especially if it is proposed to take water therefrom for public supply purposes, it is necessary to ascertain what sources of pollution can be removed, and what standard should be adopted for sewage effluents which must continue to be discharged into the stream. The distance of the outfalls from the proposed intake and the relative amounts of effluent and river water under various conditions must be ascertained. The nearer the source of pollution is to the intake, the greater the danger, and the worse the character of the sewage effluent, the farther down the river will its effect be felt. There is no obligation upon any authority to purify a sewage to more than a reasonable extent. In connection with this aspect of the case, the views of the Royal Commission on Sewage Disposal must be borne in mind. The following "summary" and table are often useful for reference. Both are taken from Vol. I. of the Eighth Report of the Commissioners:—

¹ It is found that the dissolved oxygen absorbed in 5 days at 18° C. differs little from that absorbed in 3 days at 27° C.

“(a) The law should be altered so that a person discharging sewage matter into a stream shall not be deemed to have committed an offence under the Rivers Pollution Prevention Act, 1876, if the sewage matter is discharged in a form which satisfies the requirements of the prescribed standard.

“(b) The standard should be either the general standard or a special standard which will be higher or lower than the general standard as local circumstances require or permit.

“(c) An effluent, in order to comply with the general standard, must not contain as discharged more than 3 parts per 100,000 of suspended matter, and with its suspended matters included must not take up at 65° F. (18·3° C.) more than 2 parts per 100,000 of dissolved oxygen in five days. This general standard should be prescribed either by Statute or by Order of the Central Authority, and should be subject to modifications by that Authority after an interval of not less than ten years.

“(d) In fixing any special standard the dilution afforded by the stream is the chief factor to be considered. If the dilution is very low, it may be necessary for the Central Authority, either on their own initiative or on application by the Rivers Board, to prescribe a specially stringent standard, which should also remain in force for a period of not less than ten years.

“(e) If the dilution is very great, the standard may, with the approval of the Central Authority, be relaxed or suspended altogether. Our experience leads us to think that as a general rule, if the dilution, while not falling below 150 volumes, does not exceed 300, the dissolved oxygen absorption test may be omitted, and the standard for suspended solids fixed at 6 parts per 100,000. To comply with this test, no treatment beyond chemical precipitation would ordinarily be needed. If the dilution, while not falling below 300 volumes, does not exceed 500, the standard for suspended solids may be further relaxed to 15 parts per 100,000. For this purpose, tank treatment without chemicals would generally suffice if the tanks were properly worked and regularly cleansed. These relaxed standards should be subject to revision at periods to be fixed by the Central Authority, and the periods should be shorter than those prescribed for the general or for the more stringent standards.

“(f) With a dilution of over 500 volumes, all tests might be dispensed with, and crude sewage discharged, subject to such conditions as to the provision of screens or detritus tanks as might appear necessary to the Central Authority.”

“The Central Authority will naturally pay special attention to waters which are to be used for potable purposes, and in the case of such water any application for alteration of the general standard would be closely scrutinised.”

The recommendations of the Royal Commission have not been legalised by Parliament, but in Bills before Parliamentary Committees and in Courts of Law they are generally quoted.

The Table on p. 271 bears upon the question of the quality of sewage effluents permissible under different conditions. They are sufficiently stringent to prevent, if complied with, any nuisance arising from the discharge of an effluent into a stream. In certain cases it has been held that they err rather on the side of being unduly stringent, especially with effluents such as can now be produced by properly controlled sewage works using well-known bacterial systems of purification, as such effluents will not putrefy however long they are kept in an undiluted condition.

Keeping Quality or Stability of Effluents. Usually a good effluent is odourless, or has only an earthy odour. It should not be urinous or smell of sewage or be otherwise offensive.

After two days' incubation at 37° C., no change either in the appearance or the odour of the effluent should take place.

With unsatisfactory and inadequately purified effluents, putrefaction occurs, with blackening of the liquid, and the production of an offensive odour.

A large experience of this incubator test has convinced us of its value in confirming the opinion based on the analytical results, and in indicating the suitability or otherwise of the effluent for discharge into a stream. Incubation for five days at 27° C. is sometimes carried out, but we prefer the test at the higher temperature since the result is obtained sooner, and it is probably the more stringent test in the majority of cases.

The oxygen absorbed from permanganate in three minutes at 27° C. determined before and after five days' incubation of the effluent at 27° C. (incubated in a completely filled and stoppered bottle) is also used as a stability test. With good effluents the absorption after five days' incubation does not exceed that at the beginning.

In the Ministry of Health Report, Scudder's qualitative method for dissolved oxygen absorption is also described as a stability test for sewage effluents. Portions of the aerated effluent mixed with tap water are incubated at 18.3° C. and the separate portions tested on successive days for the presence of residual oxygen, the test being made with reduced indigo carmine solution.

Another method for gauging the stability of an effluent, which appears to be more often used in America than in this country, is based on the time which an effluent requires to decolourise methylene blue under standard conditions.

We have tried all these tests, and, for simplicity and general utility in the examination of sewage effluents, find none better than the incubator test at 37° C. and "the oxygen absorbed from permanganate in three minutes' test" applied before and after incubation of the sample.

Stability in an effluent is of the greatest importance, particularly in the case of streams which are stagnant or where the dilution they afford is comparatively small.

The Sterilisation of Sewage Effluents. However satisfactory a sewage effluent may be, as gauged by chemical analysis, it is still bacteriologically impure and living bacteria of the typhoid-paratyphoid

TABLE I

Type of Sewage Liquor or Effluent.	Dissolved oxygen taken up in 5 days by typical sewage liquors of various kinds.	Dilution theoretically permissible to give a mixture not taking up more than 0.4 part per 100,000 dissolved oxygen in 5 days.		
		A. With very clean river water taking up 0.1 part dissolved oxygen in 5 days.	B. With clean river water taking up 0.2 part dissolved oxygen in 5 days.	C. With fairly clean river water taking up 0.3 part dissolved oxygen in 5 days.
1. A very good filter effluent .	0.5	0.33 dilution.	0.5 dilution.	1.0 dilution.
2. A standard effluent .	2.0	5.0 dilutions.	8.0 dilutions.	16.0 dilutions.
3. A bad effluent from filtration .	5.0	15.0 "	23.0 "	46.0 "
4. A weak precipitation liquor .	10.0	32.0 "	48.0 "	96.0 "
5. An average precipitation liquor .	15.0	48.0 "	73.0 "	146.0 "
6. An average septic tank liquor .	20.0	65.0 "	98.0 "	196.0 "
7. A strong precipitation liquor .	20.0	65.0 "	98.0 "	196.0 "
8. A strong septic tank liquor .	33.0	109.0 "	163.0 "	326.0 "
9. An average sewage .	35.0	115.0 "	173.0 "	346.0 "
10. A strong sewage .	50.0	165.0 "	248.0 "	496.0 "

group may be present, probably to greater extent than is usually realised. Experience indicates that the existence in sewage and effluents of pathogenic bacteria in quite appreciable number may sometimes be prolonged beyond the time previously supposed, and also that they may persist for years after an outbreak of enteric disease in the district has subsided.

This raises the question of the desirability of chlorinating the effluent in such cases, and this measure is in fact sometimes practised even in the absence of the enteric fevers.

With satisfactory effluents, a dose of chlorine of 1 to 5 parts per million usually suffices. Owing to the free ammonia present, chloramines are formed. This fact may lead to delay in sterilisation unless a marked excess of chlorine is added.

Chlorination of effluents has other advantages, including the restriction of growths of higher bacteria and fungi which are apt to develop in effluent channels and pipes.

The bacteriology of sewage and effluents is dealt with in Chapter XXXIV.

Detection and Estimation of Tar Acids and Bases. The tar acids and bases are very detrimental to fish life, since about 1 part of acid per 100,000, and 0.025 part per 100,000 of the base acridine, may kill all the fish in a stream. Moreover, the action of chlorine upon these substances, even when present in most minute traces, produces strongly odorous compounds which are objectionable in a water which is required for public supply purposes.

Fox and Guage's method (*vide Journal Society of Chemical Industry*, 1922).

Reagent Required. Diazotised solution of sulphanilic acid ¹ (*vide Appendix*).

The reaction depends upon the formation of azo-dyes, when sulphanilic acid is diazotised and poured into water containing tar acids in solution after it has been rendered alkaline.

Applied in the following way, the test will detect 1 part of cresol in 1 million parts of water.

To 100 c.c. of the water to be examined add 10 c.c. of the freshly prepared diazotised mixture and follow with 10 c.c. of 8 per cent. sodium hydroxide. Upon stirring, a colour varying from yellow to red will be produced if tar acids are present. The colour varies both with the nature and quantity of the tar acid and requires several minutes to develop fully.

Phenolic substances occurring in plants also give similar dyes when treated as above. Therefore, whilst this direct test may be considered conclusive if negative or if very markedly positive, a slight positive reaction may be given by a water polluted with vegetable matter only.

To make certain that such trace is not due to plant extractives,

¹ The diazotised solution is prepared by mixing five volumes of the sulphanilic acid solution with one volume of the sulphuric acid, cooling to 4° C., and adding slowly five volumes of the sodium nitrite solution.

Fox and Guage suggest the following modification of the above test :—

One hundred c.c. of the sample are twice extracted with chloroform. This removes the tar acids, and leaves behind the plant phenoloids which are not readily soluble in chloroform. The chloroform extract is separated, the tar acids washed therefrom with 20 per cent. sodium hydroxide solution, and the test applied to this alkaline solution. The amount of alkali present influences the final depth of colour produced. It is advisable, therefore, to neutralise measured volumes of the soda extract with sulphuric acid before the addition of the diazotised reagent and the 8 per cent. sodium hydroxide. This test may be made roughly quantitative by comparison of the colours obtained with that given by standards containing known quantities of a mixture of cresol, xyleneol and β -naphthol. The presence of tarry matter can be confirmed by examining the suspected water for certain of the basic constituents of tar, such as quinoline, isoquinoline, and acridine, which give a precipitate with the usual alkaloidal reagents. They must first be isolated from the other constituents of the polluted water by shaking with chloroform which takes them into solution. The chloroform is separated and shaken with sulphuric acid (sp. gr. 1.27), and, if these bases are present, they are taken up by the acid and may be detected by the iodine, bismuth-iodide or picric acid tests. According to Fox and Guage, a quantitative result can be obtained by the picric acid method (*J.S.C.I.*, June, 1922, Trans. 173).

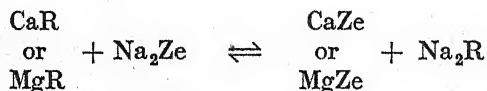
CHAPTER XX

SOFTENING OF WATER—THEORETICAL AND ANALYTICAL CONSIDERATIONS

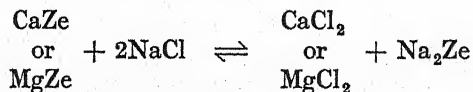
THE process of water softening is primarily concerned with the removal of calcium and magnesium. Iron and aluminium, while having soap-destroying power, are seldom found in significant quantity, and, if present in appreciable amounts, they are objectionable on other grounds. The salts of calcium and magnesium normally found in natural waters are the bicarbonates $[\text{Ca}(\text{HCO}_3)_2]$ and $[\text{Mg}(\text{HCO}_3)_2]$, the sulphates $[\text{CaSO}_4]$ and $[\text{MgSO}_4]$ and less frequently the nitrates and chlorides $[\text{Ca}(\text{NO}_3)_2]$, $[\text{Mg}(\text{NO}_3)_2]$, $[\text{CaCl}_2]$ and $[\text{MgCl}_2]$ (see page 305).

The calcium and magnesium salts are converted by lime and sodium carbonate to calcium carbonate and magnesium hydroxide, which substances are precipitated from solution.

In the base-exchange process of softening, a natural or synthetic "zeolite" is employed. Zeolites are complex sodium aluminium silicates and remove hardness by substituting sodium for the calcium and magnesium present in the water. The process is demonstrated by the equation :—

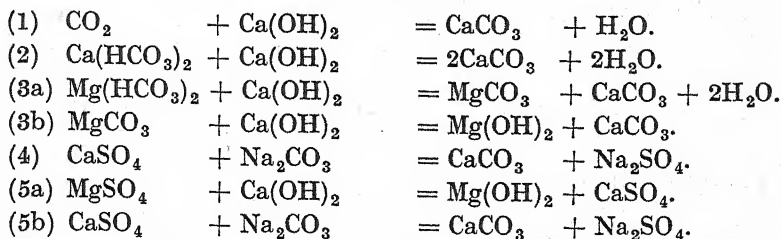


where R represents the anion attached to the calcium and magnesium, and Ze the alumino-silica complex attached to the sodium. The process is reversible and the zeolitic softening beds are regenerated by passing sodium chloride solution through them. The calcium and magnesium held by the exhausted material are removed in the effluent thus :—



In all cases where softening is under consideration, the free carbon dioxide and the saline constituents of the water should be determined. When this is done, the amount of lime or of lime and sodium carbonate theoretically necessary to soften can be calculated. Unfortunately, theory and practice often disagree. The carbonates of calcium and magnesium and magnesium hydroxide are all slightly soluble in water, but the solubility varies with the temperature of the water and with the nature and amount of the other saline constituents. To obtain the most complete softening effect a slight excess of reagent has often to be added.

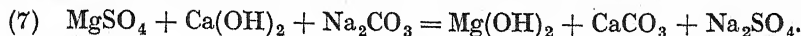
Lime and Lime-soda Softening. The processes of lime and lime-soda softening are illustrated by the following equations. The first of these, showing the reaction of carbon dioxide with lime, is given, since the reaction must always be considered in calculating the theoretical quantities of lime required for softening.



Equations (3a) and (3b) may be converted to a single equation :—

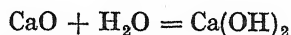


Similarly equations (5a) and (5b) may be written :—



The chlorides and nitrates of both calcium and magnesium react in a similar manner to the sulphates.

In practice, the lime (CaO) always reacts, as shown above, in the form of calcium hydroxide $[\text{Ca(OH)}_2]$, the quicklime being “slaked” and used as a slurry (“milk of lime” or “lime cream”) or as clear, settled lime water. Occasionally the solid calcium hydroxide (hydrated lime) is apportioned to the water by a “dry-feed” machine. Slaking of lime is shown by the equation :—



and, if just the required equivalent of water is used, the “hydrated lime” obtained is a dry, easily handled product. However, since it is common practice to handle and weigh lime (CaO), the quantities required are usually calculated in terms of this radical. Similarly, the bicarbonates of calcium and magnesium present in solution are expressed in terms of the respective carbonates. This also is partly due to convention, partly to the fact that the molecular weight of calcium carbonate is practically a round figure of 100. The factors required in calculating the theoretical equivalents in the equations given above, the analytical figures being in parts per 100,000, are as follows :—

$$(1) \quad [\text{Free carbon dioxide (CO}_2)] \times 0.127 = \text{lbs. of lime (CaO) required per 1,000 gallons of water.}$$

$$(2) \quad \left[\begin{array}{l} \text{Calcium bicarbonate, in terms of} \\ \text{calcium carbonate (CaCO}_3) \end{array} \right] \times 0.056 = \text{lbs. of lime (CaO) required per 1,000 gallons of water.}$$

$$(3a), (3b) \text{ and } (6) : \left[\begin{array}{l} \text{Magnesium bicarbonate, in terms of} \\ \text{magnesium carbonate (MgCO}_3) \end{array} \right] \times 0.133 = \text{lbs. of lime (CaO) required per 1,000 gallons of water.}$$

(4) $\left[\begin{array}{l} \text{Calcium sulphate, chloride, nitrate,} \\ \text{in terms of calcium (Ca)} \end{array} \right] \times 0.265$
 = lbs. of sodium carbonate (soda-ash, Na_2CO_3) required per
 1,000 gallons of water.

(5a), (5b) and (7) :

$\left[\begin{array}{l} \text{Magnesium sulphate, chloride, nitrate,} \\ \text{in terms of magnesium (Mg)} \end{array} \right] \times 0.231$
 = lbs. of lime (CaO) required per 1,000 gallons of water.

$\left[\begin{array}{l} \text{Magnesium sulphate, chloride, nitrate,} \\ \text{in terms of magnesium (Mg)} \end{array} \right] \times 0.436$
 = lbs. of sodium carbonate (soda-ash, Na_2CO_3) required per
 1,000 gallons of water.

Conversions :—

(lbs. per 1,000 gallons) $\times 10$ = parts per 100,000.

(lbs. per 1,000 gallons) $\times 7$ = grains per gallon.

The following examples demonstrate the use of these factors.

Example 1.

The analytical figures of a Hertfordshire chalk water were :—

Free CO_2 2.8 parts per 100,000.

Calcium bicarbonate as CaCO_3 . . . 24.5 " " "

Magnesium bicarbonate as MgCO_3 . . . 4.2 " " "

The small residual of magnesium and calcium salts was not considered.

The free CO_2 requires 2.8×0.127 , *i.e.*, 0.36 lbs. of lime (CaO) per 1,000 gallons of water.

The calcium bicarbonate requires 24.5×0.056 , *i.e.*, 1.37 lbs. of lime (CaO) per 1,000 gallons of water.

The magnesium bicarbonate requires 4.2×0.133 , *i.e.*, 0.56 lbs. of lime (CaO) per 1,000 gallons of water.

The total theoretical amount required is 2.29 lbs. of lime (CaO) per 1,000 gallons of water,

= 16.0 grains per gallon,

= 22.9 parts per 100,000.

Example 2.

A water from the Coal Measures gave the following results upon analysis :—

Free CO_2 2.2 parts per 100,000.

Calcium bicarbonate as CaCO_3 . . . 29.4 " " "

Magnesium bicarbonate as MgCO_3 . . . 5.5 " " "

Magnesium sulphate as Mg. 2.5 " " "

The free CO_2 requires 2.2×0.127 , *i.e.*, 0.28 lbs. of lime (CaO) per 1,000 gallons of water.

The calcium bicarbonate requires 29.4×0.056 , *i.e.*, 1.65 lbs. of lime (CaO) per 1,000 gallons of water.

The magnesium bicarbonate requires 5.5×0.133 , *i.e.*, 0.73 lbs. of lime (CaO) per 1,000 gallons of water.

The magnesium sulphate requires 2.5×0.231 , *i.e.*, 0.58 lbs. of lime (CaO) per 1,000 gallons of water.

The magnesium sulphate requires 2.5×0.436 , *i.e.*, 1.09 lbs. of soda-ash (Na_2CO_3) per 1,000 gallons of water.

Total theoretical amount of lime (CaO) required is 3.24 lbs. per 1,000 gallons of water,

$$= 22.7 \text{ grains per gallon,}$$

$$= 32.4 \text{ parts per 100,000.}$$

Theoretical amount of soda-ash (Na_2CO_3) required is 1.09 lbs. per 1,000 gallons of water,

$$= 7.6 \text{ grains per gallon,}$$

$$= 10.9 \text{ parts per 100,000.}$$

The amount of lime and sodium carbonate of commerce which would be required would depend upon the quality of the chemicals used.

For experimental purposes it is best to saturate a portion of the water under examination with slaked lime, filter, and estimate the amount of CaO and CaCO_3 in the solution. The amount of the latter must be taken into consideration, or the strength of the lime water will be over-estimated.

To 10 c.c. of the filtered lime water, in a Nessler glass, add a few drops of phenolphthalein solution and a single drop of delicate methyl orange solution. Stand the Nessler glass on a white plate and add from a burette N/10 acid, drop by drop, until the red colour has disappeared. Note the amount used, and continue the addition of the acid until the orange tint, due to the action of free acid upon methyl orange, appears. With a little experience, using the above quantities, excellent results are obtainable. The amount of acid used in the first instance may be called *a*, and the total amount used *b*. *a* represents the amount of acid required to neutralise the lime present, plus the amount required to convert the carbonates in solution into bicarbonates (*i.e.*, half the amount actually required to decompose the carbonate), whilst *b* will represent the amount required to neutralise the lime and decompose the carbonates and bicarbonates.

Then $2a - b$ = number of cubic centimetres of acid equivalent to the CaO, and this multiplied by 2.8 gives the number of milligrammes of CaO.

$2(b - a)$ = number of cubic centimetres equivalent to the carbonate, and multiplied by 5 gives the amount of carbonate in the solution. Benzene-azo- α -naphthylamine can be used instead of methyl orange.

In estimating the amount of lime water to be used, it must be remembered that it has been made with the hard water, and that all the free CO_2 and most of the CaCO_3 in the original water has been removed, and the MgSO_4 present has been converted into CaSO_4 .

The amount of lime water required in an experiment using 1 litre of the water is easily calculated, since it applies to the litre only, but

the amount of sodium carbonate required is the amount required by the litre plus that required by the lime water added.

Taking the sulphated water just referred to, and assuming that the lime water made from it contained 1.2 mg. CaO in each cubic centimetre, then 270 c.c. of this should be added to the litre of water, and the amount

of pure Na_2CO_3 required would be $\frac{(1,000 + 270)}{100} \times 10.9 \text{ mg.} = 188 \text{ mg.,}$

which is finally added to the mixture, gently stirred for some minutes, and then left to settle. The rapidity of clarification is always worth recording. At intervals, 100 c.c. can be filtered off and examined by the method used for the lime water, but it is advisable to titrate with N/50 acid.

If $2a$ exceeds b , then some hydroxide is present, and the following equations are used to estimate the hydroxide and carbonate in solution :—

$2a - b$ = number of cubic centimetres of acid equivalent to the hydroxide.

$2(b - a)$ = number of cubic centimetres of acid equivalent to the carbonate.

When $2a$ is less than b , no hydroxide can be present, and the following equations are used to estimate the carbonate and bicarbonate in solution :—

$2a$ = acid equivalent to carbonate.

$b - 2a$ = acid equivalent to bicarbonate.

Where N/50 acid is used, each cubic centimetre represents 1 mg. of calcium carbonate and 0.56 mg. of lime (CaO), or 0.74 mg. of the hydroxide $\text{Ca}(\text{OH})_2$.

In waterworks practice, pH indicator solutions are used to control lime softening processes. Thus, thymol violet gives a yellow colour with untreated water, and after lime has been added the colour changes through green to blue, and, when the tint is a greenish-blue, the amount of alkali added is about correct. With a green colour the alkali is insufficient; with a violet-blue colour it is in excess. A series of standard tints can be prepared and kept in sealed tubes for comparison, and the water tested should be perfectly clear and bright. Brilliant cresyl blue, however, is the best indicator for the excess lime process of purification. So long as the water contains no excess lime it gives a pure blue colour with this reagent. The slightest trace of lime imparts a green tint, and with a marked excess, say, 2 parts per 100,000, the colour becomes brown. Apparatus for the automatic continuous recording of pH are available, and are very valuable in the control of water softening plant (see p. 209).

If the water passed into the mains contains on some occasions an excess of lime, and on others a deficiency, action will take place and a little chalk will be deposited. Generally, however, these deposits occur because the water is passed into the mains before the action of the lime or soda is complete. The effect of time is indicated in the following table, giving the results of experiments made with the chalk water

previously mentioned. The lime water made from it contained 1.2 mg. CaO in each cubic centimetre.

For ascertaining the best proportion of lime water to use, $\frac{1}{2}$ litre of water was placed in each of four litre cylinders, and 20, 22, 24, and 26 c.c. of lime water added per 100 c.c. of the water contained in the respective cylinders. The water was gently agitated as the lime water

Proportion of Lime Water.	Time.	Value of		CaO in mg.	Soap test hardness.
		a.	b.		
		in c.c.	in c.c.		
20 c.c. to 100 of water .	$\frac{1}{4}$ hour.	0.6	1.7	0.0	—
" " " "	1 "	0.6	1.65	0.0	8
22 c.c. to 100 of water .	$\frac{1}{4}$ "	1.3	2.3	0.85	—
" " " "	1 "	0.9	1.6	0.55	8 $\frac{1}{2}$
" " " "	2 hours.	0.85	1.5	0.55	8
24 c.c. to 100 of water .	$\frac{1}{4}$ hour.	1.55	2.1	2.8	—
" " " "	1 "	1.1	1.5	1.95	—
" " " "	2 hours	1.1	1.5	1.95	6 $\frac{1}{2}$
" " " "	3 days	0.5	1.0	0.0	6
26 c.c. to 100 of water .	$\frac{1}{4}$ hour	3.1	5.0	3.4	—
" " " "	1 "	1.55	1.9	3.4	8
" " " "	2 hours	1.25	1.55	2.7	—
" " " "	3 "	1.0	1.25	2.1	6

was being added. After standing various periods, portions were filtered off and examined.

With an excess of lime, the action appeared to be retarded. The specimen which was kept three days had undergone a change upon keeping, since the whole of the excess lime had disappeared and some of the calcium carbonate had been deposited. The last sample showed very little action during the first quarter hour, but within the hour most of the calcium carbonate had been deposited. Before the CaCO_3 assumes the crystalline condition in which it is ultimately deposited, it probably passes through the colloidal state ; otherwise it seems impossible to explain how the filtered waters, free from carbonic acid, could retain more than traces of calcium carbonate in solution.

There could be no doubt from the above results that, with this particular water, 200 gallons required converting into lime water and adding to 1,000 gallons of the original water to give the best results, since the treated water contained no excess lime.

The coal measure water referred to was extremely difficult to treat, inasmuch as it varied greatly in character. It was derived from a disused mine containing 400 feet of water. Samples taken at various levels down to 300 feet showed a gradual increase in hardness. When the water was being pumped, the hardness increased as the water level fell. Moreover, there was often a distinct change in character. The sample referred to contained carbonates of calcium and magnesium and magnesium sulphate, whereas the next sample sent contained calcium carbonate and sulphate and magnesium sulphate, but no magnesium

carbonate. The amount of lime required for softening had been calculated from results obtained with the first sample, but it was soon found that chalk was depositing in the mains and that the water was not being properly softened to 26 parts per 100,000. The tests employed at the works proved useless. Phenolphthalein gave a marked reaction when the lime added was far from being sufficient, and silver nitrate did not give a definite reaction unless a marked excess of lime was being used.

A carboy of what was considered an average sample of the water was taken and used in the following experiments. Upon analysis the water was found to contain :—

Calcium carbonate	.	.	.	29.2	parts per 100,000
Calcium sulphate	.	.	.	1.0	" "
Magnesium sulphate	.	.	.	15.3	" "
Sodium sulphate	.	.	.	5.3	" "
Sodium chloride	.	.	.	4.5	" "
Free carbonic acid	.	.	.	1.1	" "
Total solids	.	.	.	56.1	" "

From the analysis it would appear to be an easy matter to soften this to 26 parts per 100,000, yet this can be practically effected (without the use of sodium carbonate) only by using a large excess of lime water.

The lime water used in the experiments was made with the water to be softened and contained 110 parts of lime (CaO) per 100,000.

The CO_2 required $1.1 \times 0.127 = 0.14$ lb. of lime (CaO) per 1,000 gallons of water.

The calcium bicarbonate (as CaCO_3) required $29.2 \times 0.056 = 1.63$ lbs. of lime (CaO) per 1,000 gallons of water.

Total lime (CaO) required = 1.77 lbs. per 1,000 gallons of water,
 = 17.7 parts per 100,000,
 = 16 c.c. of lime water per 100 c.c. of water.

The magnesium sulphate required :

$3.1^1 \times 0.231 = 0.71$ lb. of lime (CaO) per 1,000 gallons of water,
 = 7.1 parts per 100,000,
 = 6.5 c.c. of lime water per 100 c.c. of water.

Total lime water required = 22.5 c.c. per 100 c.c. of the raw water.

This quantity was added to the water, and after standing all night the water was analysed with the following results, expressed in parts per 100,000 :—

Ca 5.5, Mg 0.5, CO_3 1.5, SO_4 16.5, Cl 2.7, NO_3 0.06.

Calcium carbonate	.	.	.	.	.	2.5
Calcium sulphate	.	.	.	.	.	15.3
Magnesium sulphate	.	.	.	.	.	2.4
Sodium sulphate	.	.	.	.	.	5.6
Sodium chloride	.	.	.	.	.	4.5
Total solids	.	.	.	.	.	33.5

¹ 3.1 = the residual magnesium = the magnesium in 15.3 parts of MgSO_4 .

A sample which had stood only four hours contained free alkali, and gave, upon analysis, the following results :—

MgO	.	.	.	.	.	0.75	parts per 100,000
CaO	.	.	.	.	.	0.5	„ „
CaCO ₃	.	.	.	.	.	1.75	„ „

The following experiments were made with this water : 200 c.c. were placed in each of six cylinders, and 14, 16, 18, 20, 22 and 24 c.c. of lime water per 100 c.c. added to the respective samples. At the end of an hour, all were filtered and examined, with the following results :—

Lime water per 100 c.c.	a.	b.	CaO in mg.	Hardness parts per 100,000
14 c.c. . . .	0.4	1.6	0.0	32
16 „ . . .	0.65	1.4	0.0	32
18 „ . . .	0.9	2.0	0.0	33
20 „ . . .	1.0	1.7	0.5	32
22 „ . . .	0.85	1.2	1.4	30
24 „ . . .	0.9	1.2	1.7	25

Apparently the best results were obtained by using even more lime water than was required for both carbonates and sulphates ; therefore an endeavour was made to check these results by experiments in which larger quantities of water were used (500 c.c.) and by examination of the filtrates at various intervals. The results did not coincide, and emphasised the difficulty of predicting exactly what would occur.

A number of other experiments were made, all of which tended to show that time is an important factor in the softening process, and that magnesia, $\text{Mg}(\text{OH})_2$, more rapidly precipitates than CaCO_3 . When lime water is added to a solution of calcium bicarbonate, several days are required for completion of the reaction, unless the temperature is raised. After six hours, however, the amount of CaCO_3 formed or deposited is very small. The after-deposits occurring in softened water rarely contain any magnesia. The slower deposition of the lime salt is due to the fact that the CaCO_3 is crystalline, whereas the magnesium hydroxide deposits in an amorphous condition. The action of sodium carbonate on calcium and magnesium sulphate is still slower and less complete.

It is difficult to predict exactly what will take place when the softening chemicals are added to a hard water, and we have concluded that the results obtained in the laboratory can be used only as a guide for further experiments on a larger scale. Continuous gentle agitation assists in the flocculation and deposition of the precipitate.

The one object of such experiments is to ascertain the amount of chemical required to cause the maximum reduction of the hardness without leaving any free lime in the water. In making large scale experiments we prefer to weigh out the actual quantities of lime and

soda required, and to convert the former into a thin milk of lime by grinding in a mortar with 10 per cent. of the water, and dissolving the latter in a small quantity of the water. Where both chemicals are being used, tests can be applied to ascertain if there is any advantage in adding the one or the other first, or of adding both at the same time.

When the experiments are to determine the amount of lime needed to give an excess which will destroy bacteria, this excess can be determined volumetrically or by the use of an indicator (brilliant cresyl blue). We find that 1.5 parts of excess lime per 100,000, with twenty-four hours' contact, invariably destroys coliform bacteria in river waters, and that such water gives a green tint with this indicator. The excess lime has then to be removed by agitation with air containing free carbonic acid before it is safe to turn the treated water into the main.

When river waters are being treated, it must be remembered that the total hardness and temporary hardness may vary considerably, and that the amount of lime added must be varied accordingly. With one river water we found that, during a period of six months, the amount of lime required per 1,000 gallons varied from 1 lb. 11½ oz. to 2 lb. 8 oz. The lime is also liable to change on storage. When fresh it may contain 93 per cent. of CaO, and after a few weeks only 87 per cent. Again, in each installation there appears to be a loss of lime, possibly because the whole does not dissolve and an allowance must also be made for the loss. In our experimental station, we found this loss averaged 1 part CaO per 100,000 of the water treated with milk of lime, but was much less when lime water was used. In water softening processes, lime water acts more rapidly, and is more reliable in its effects, than milk of lime. It should be frequently tested since the strength may vary.

On page 207 a useful table will be found giving the colour changes of a number of indicators with varying pH.

When Na_2CO_3 is added to water containing calcium or magnesium sulphate, the CaCO_3 or MgCO_3 formed appears to remain in colloidal condition, and only slowly aggregates and deposits.

Hydrated lime is frequently used instead of caustic lime in small softening installations. It is obtainable in finely powdered form, and is, therefore, easily handled, and suitable for dry-feed apparatus or for the preparation of lime cream.

When hydrated lime is used, the weight of chemical added must be increased by one-third, since 1 part CaO is equivalent to 1.32 parts $\text{Ca}(\text{OH})_2$.

Base-Exchange Softening. The analytical information required when this method of softening is under consideration is similar to that required for lime softening. The economy of the base-exchange process depends essentially on the amount of salt required to regenerate the zeolite beds, and on the calcium and magnesium content of the water being softened. A particular zeolite requires a certain quantity of salt, bearing a constant ratio to the calcium and magnesium being removed from the bed in its regeneration. The quantity of salt consumed in softening is calculated from the calcium and magnesium content of the

water and the salt/hardness ratio. It is usual to express the calcium and magnesium figures as lime (CaO). Thus if a base-exchange material has a salt/hardness ratio (NaCl/CaO) of 4 : 1 and a water has a hardness, expressed as CaO, of 14.0 parts per 100,000, then 1.4 lbs. of CaO would be removed from each 1,000 gallons of water, in softening to zero, and 4.0×1.4 , *i.e.*, 5.6 lbs. of salt (NaCl) would be required per 1,000 gallons of water softened to zero.

Other analytical items of importance are :—

(1) Free CO₂, iron, manganese, organic and suspended matter contents. These in quantity deleteriously affect zeolite material, particularly the synthetic varieties.

(2) Alkalinity. The softened water may be unduly corrosive if this figure is excessive.

(3) Chloride content. An excessive quantity of chloride may affect the softening capacity of the zeolite.

Further details of water softening will be found in Chapter XLIII.

CHAPTER XXI

THE DETERMINATION OF THE ACTION OF WATER ON LEAD

In the examination of waters used for drinking and domestic purposes, the action on lead is a matter of great importance, and it should always be considered since lead is very commonly used for service pipes, domestic pipes and fittings.

Indications, or suspicions, that a water is likely to acquire lead by contact with lead pipes and fittings can be obtained from the analyses of samples.

The factors which determine the action of plumbo-solvent waters are complex and not fully understood, and no strict correlation between cause and effect has been established.

Practically all waters have a slight action on new lead pipes, but in most cases it is only transient and insufficient to be harmful. Particles of lead left in pipes from cutting and jointing often account for apparent initial action, and normally the internal surfaces of the pipes quickly acquire a protective covering, after which no further lead is taken up by the water.

With certain types of water, however, no such protective coating is developed, or its formation may be exceedingly slow, when the acquisition of lead by the water is long continued, and may lead to plumbism amongst the consumers.

Two well-defined types of waters behave in this manner and are characterised on analysis by the following features :—

Group.	1.	2.
Source.	Upland and Moorland Gathering Grounds. Often Peaty.	Wells, usually Shallow.
pH.	On Acid Side of Neutrality.	On Acid Side of Neutrality.
Total Solids	Low	High or Moderate.
Carbonate Alkalinity	Low	Low
Temporary Hardness	Low	Low
Permanent Hardness	Low	High
Total Hardness	Low	High or Moderate
Nitrogen in Nitrates	Low	High
Oxygen Absorbed	High	Normal.

Characters common to both types are the comparative absence of bicarbonates of calcium and magnesium and a pH value below 7.0. Serious plumbism has resulted from the use of waters of both types, and the popular belief that only soft waters are dangerous with lead is a fallacy. A water which is found on analysis to be highly nitrated, to

have considerable hardness, mostly permanent, and a low pH value, should be suspected of possessing serious plumbo-solvent properties.

Waters with low pH values due to the presence of free carbon dioxide are not necessarily plumbo-solvent, and, in fact, seldom are so, since the majority contain an appreciable amount of bicarbonates.

Waters which have been softened by the lime process are safe with lead, as are also base-exchange softened waters except when the hard water possesses plumbo-solvent action, such as those of Group 2, mentioned above.

Apart from the indications given by analysis, other methods are available for assessing the plumbo-solvent action of waters, including laboratory and field experiments, and, where the supply is in service and lead pipes in use, the determination of the amount of lead present in the water delivered to consumers.

Many laboratory tests have been devised to assess plumbo-solvency, and reference should be made to Technical Paper No. 4, Water Pollution Research, Department of Scientific and Industrial Research, entitled "The Action of Water on Lead with Special Reference to the Supply of Drinking Water," for an account of the methods employed and the results obtained.

The interpretation of the results of laboratory tests with an unknown water is often very difficult, and a long period of time is required for repeated experiments. The findings thus obtained must be correlated with those of waters known by actual experience in service to be safe and unsafe respectively.

The laboratory method which we employ as an aid in assessing the plumbo-solvency of a water is as follows:—

A white-glass stoppered bottle of 200 c.c. capacity, known to yield no lead with either alkaline or acid waters, is filled with the water under test.

A strip of pure lead foil, measuring 3 inches by 1 inch, is then polished to a uniform brightness by rubbing, first with a little petroleum ether containing a trace of the finest emery powder in suspension, then with a clean dry cloth. The foil is shaped on a glass rod into a cylinder, the lead being handled with a cloth and contact with the fingers avoided. The foil is then placed in the water, the stopper of the bottle lightly inserted, avoiding the inclusion of air bubbles, and the bottle stood aside and maintained at approximately 20° C. for twenty-four hours. At the end of this time the appearances of both the water and the lead foil are noted. 100 c.c. of the water are then decanted from the bottle, and the lead in this portion is estimated by the method described on p. 253. This lead represents that which is in solution and colloidal suspension. The foil is now removed from the bottle, care being again taken to avoid contact with the fingers, and transferred into a fresh and similar portion of the water sample. This specimen is carefully stoppered and put aside for a further twenty-four hours as before.

3 c.c. of the gel acetic acid, as used in the lead determination, are added to the 100 c.c. of the original sample remaining from the first

twenty-four hours' test, and it is kept mixed in the bottle until all the deposited lead is dissolved. An estimation of this lead is made as before, but the addition of the acetic acid is omitted.

The total lead present is then recorded in the following manner :—

If A is the number of milligrams of lead found in the first 100 c.c. of water decanted from the bottle, and B the number of milligrams of lead in the second 100 c.c., then :—

A = the concentration of colloidal and soluble lead.

$$\frac{B - A}{2} = \text{the concentration of deposited lead.}$$

$$\frac{A + B}{2} = \text{the concentration of the total lead removed from the foil.}$$

All expressed as Pb in parts per 100,000.

This test can be repeated on many successive days, using the same piece of foil, in order to ascertain whether prolonged contact with the water produces a protective coating on the lead. The duration of the experiment must be decided according to the results obtained, and it need not be continued if the results of analysis are satisfactory and the first day's test indicates that the water has no plumbo-solvent action.

The test may be elaborated by determining the oxygen which is taken up by the lead during the test. In order to obtain this figure, two other bottles of the same dimensions as the first, one of which contains a cylinder of lead foil prepared as before, are filled with the sample. These are kept for the period of twenty-four hours, when the dissolved oxygen content of each is determined. The difference in the dissolved oxygen of these two portions represents that oxygen which has combined with the lead.

The results obtained in these and similar experiments depend on the exact procedure followed, and the findings of different workers are not comparable unless the conditions of test are identical. In practice, the experience gained by examining a large number of waters, adhering strictly to one standardised method, enables a reasonably correct interpretation of the results to be made.

The laboratory test for the action of water on lead is stringent, and if a sample examined in this manner takes no lead into solution and gives satisfactory analyses, it can be stated with confidence that the water is non-plumbo-solvent, and lead pipes can be used with safety. If, however, a positive result is obtained, the water is not necessarily plumbo-solvent in actual use. Thus, figures approaching 0.2 part of lead per 100,000 are obtained in the first day's test with waters which behave in service in an entirely satisfactory manner in respect of their action on lead pipes. The repeated application of fresh water to the same lead foil, as described above, may give definite indication, by a fall in the figures obtained, that the water, though initially aggressive, forms a protective coating on the surface

of the metal. In one instance, for example, in which lead pipes had been in use for a number of years and no plumbism had been recorded, the water ceased to acquire lead from the foil in this test only after twenty consecutive days of treatment. In cases such as this, and when laboratory tests prove inconclusive, analyses for lead made on samples of water collected from lead services are of great value. Such samples should be taken after the water has been stagnant in the pipes over-night, and also at times of normal draw-off during the day. It may be found that samples collected after long standing in the pipes contain less lead than samples collected after short standing, owing to particulate lead compounds not being flushed into the sampling bottle.

There are many factors other than the character of the water and the period of contact which influence the results, such as temperature, the length, diameter and position of the lead pipe, union of the pipe with other metals, such as copper, the earthing of electric currents thereto, etc.

The following typical examples (Table I) show the results obtained by the test described above in the examination of several water supplies of different characters :—

1. A typical, hard, Chalk-derived water.

This water has no plumbo-solvency as indicated by analysis and laboratory tests, and lead pipes are used with satisfaction.

2. A hard, river-derived water, purified by storage, sand filtration and ammonia-chlorine sterilisation.

This water shows slight action on lead by laboratory test, but this is soon arrested in practice and lead pipes are used with satisfaction.

3. A soft, upland water from impounding reservoir.

This water has plumbo-solvency as indicated by laboratory tests and experience, and lead pipes cannot be used with safety.

4. A soft, upland water from impounding reservoir.

This water has no plumbo-solvency as indicated by laboratory tests and experience, and lead pipes are used with safety.

5. A hard water with low pH and carbonate alkalinity and a high nitrate content.

This water has plumbo-solvency as shown by laboratory tests and experience, and lead pipes cannot be used with safety.

In examples Nos. 1, 2 and 4, samples, collected from consumers' taps fed by lead service pipes, were found to contain no lead either during normal running of water or after long standing in the pipes. In Nos. 3 and 5, however, lead was present in samples collected under both conditions, even though the lead pipes had been in use for several years.

It will be noticed from these examples that a completely negative result was obtained in the case of the hard Chalk water. This is usual with Chalk waters derived from underground sources, although the free CO_2 content may be high, but example No. 2, which is a purified river-derived water, is substantially a Chalk water in respect of its origin, total solids and bicarbonate content. The action on lead shown by laboratory test in this case is quite typical and the presence of organic matter and ammoniacal compounds probably account for this

TABLE I
RESULTS EXPRESSED IN PARTS PER 100,000

Water Number.	1	2	3	4	5
pH	7.2	8.0	6.6	7.0	5.4
Free CO ₂	2.6	0.4	0.4	0.6	2.4
Alkalinity, as CaCO ₃	23.5	19.5	0.6	4.0	0.5
Total Hardness	23.0	26.0	2.5	5.0	18.0
Permanent Hardness	6.5	8.5	2.5	3.5	18.0
Nitrogen in Nitrates	0.36	0.24	0.00	0.00	2.2
Oxygen Absorbed from Permanganate, 4 hours at 27° C.	0.010	0.160	0.205	0.420	0.020
Action on Lead, Laboratory Test, Total Lead, as Pb, taken up in 24 hours—					
1st Test	0.00	0.17	0.22	0.14	0.40
2nd Test	0.00	0.13	0.35	0.12	0.55
3rd Test	0.00	0.13	0.40	0.08	0.65
4th Test	0.00	0.14	0.33	0.05	0.60
5th Test	0.00	0.14	0.35	0.04	0.65

result. Our experiments have indicated that the amount of lead taken up by different samples of the same supply tends to increase according to the organic impurity as indicated by the albuminoid ammonia and oxygen absorbed. It is also increased by ammonia-chlorine sterilisation, and appears to be accentuated when nitrites are produced, such as is ultimately the case in many river-derived waters, treated by this process, after contact with mains and pipes.

The following example illustrates the same point in respect of the soft, upland waters. The analyses are of two samples from the same source, the waters being practically identical in character apart from organic purity.

TABLE II

Parts per 100,000.	(a).	(b).
pH	6.6	6.6
Total Solids	6.0	6.5
Chlorine in Chlorides	1.1	1.1
Alkalinity, as CaCO ₃	0.6	0.6
Total Hardness	2.5	3.0
Nitrogen in Nitrates	0.00	0.00
Free Ammonia	0.0000	0.0000
Albuminoid Ammonia	0.0052	0.0016
Oxygen Absorbed, 4 hours at 27° C.	0.205	0.075
Action on Lead, Laboratory Test, Total Lead as Pb, taken up in 24 hours—		
1st Test	0.22	0.09
2nd Test	0.35	0.11

We have frequently observed this effect of increased plumbo-solvency according to the organic impurity of the water. The acidity of the upland, moorland peaty waters is due to vegetable organic acids, and not to free carbonic acid, but mineral acids, such as sulphuric acid, of industrial or atmospheric origin, may occasionally be present. The absence of calcium and magnesium bicarbonate is a potent factor in the plumbo-solvency of these waters, and organic compounds may cause a false result in the estimation of alkalinity by the usual titration method.

In Example 4 of Table I, it will be noted that although the water is of upland origin and contains vegetable organic matter as indicated by the high figure for oxygen absorbed, the water is not plumbo-solvent; this is explained by the comparatively high alkalinity and pH value. Soft, upland waters are not all plumbo-solvent any more than all hard waters are non-plumbo-solvent, and various factors, often working in combination, determine plumbo-solvency or otherwise.

Further investigations carried out in connection with the public water supply shown in Example 3 of Table I are instructive in showing the results obtained in field experiments. A 70 feet length of $\frac{1}{2}$ inch diameter new lead pipe was installed on the main, and water was drawn therefrom at various times of the day in much the same manner as would take place in the ordinary houses of the neighbourhood. Samples were collected of the first draw-off in the morning, after standing over-night, and also at various times later in the day until evening. These were examined for lead with the following results :—

Number of Days Lead Pipe in Use.	Total Lead, as Pb in parts per 100,000.	
	(a) When Water had Stood Over-night.	(b) After Normal Use during the Day.
1	0.30	0.45
2	0.30	0.02
3	0.25	0.05
4	0.35	0.05
5	0.48	0.02
6	0.45	0.11
7	0.26	0.02
8	0.33	0.05
9	0.29	0.06
11	0.15	0.02
13	0.30	Nil.
15	0.13	Nil.
17	0.24	Nil.
19	0.30	0.05
21	0.24	Nil.
23	0.24	Nil.
25	0.26	Nil.
27	0.23	0.05
29	0.45	0.04
36	0.22	0.02
43	0.18	Nil.

A month after the termination of this experiment the whole was repeated with similar results.

Considerable irregularity will be observed among these results, but this is usual in such experiments. It was evident, however, that the water would not produce a protective film on the pipes, but would continue to take up lead, and render the use of lead pipes dangerous to the consumers.

This was verified by collecting samples from a house where a lead service pipe had been in use for over thirty years, when it was found that the water contained lead varying from 0.06 to 0.15 parts per 100,000 at various times of the day.

An alternative to the prohibition of the use of lead pipes in the district was, of course, the treatment of the water. This subject is dealt with in Chapter XLV.

The question of plumbo-solvency is so important that another illustration of investigations carried out on this subject is worthy of study. The public water supply concerned was derived from an upland source, and received no treatment. The analyses, as shown in the following example, suggested that the water would be plumbo-solvent, and laboratory experiments carried out with the water gave the results shown in Table III :—

RESULTS EXPRESSED IN PARTS PER 100,000

pH	6.5	Chlorine in Chlorides	1.1
Alkalinity, as CaCO_3	0.40	Nitrogen in Nitrites	absent
Total Solids	4.5	Nitrogen in Nitrates	0.00
Total Hardness	1.5	Free Ammonia	0.0000
Temporary Hardness	0.0	Albuminoid Ammonia	0.0016
Permanent Hardness	1.5	Oxygen absorbed	0.025

Five series of experiments were carried out at various times, using the test previously described, in which the water was kept in contact with lead foil for twenty-four hours, and the water renewed daily for four, six or ten consecutive days. In Series I, the fall from maximum to minimum figures was fairly uniform throughout the ten days' period, but this was not consistent in the other experiments.

These tests supported the indications given by the analysis, and accordingly a 100 feet length of $\frac{1}{2}$ inch diameter new lead pipe was installed on a main and samples of water collected therefrom over a period of six weeks. These samples were obtained after long periods of stagnation and during normal running of water, and the analytical results are shown in Table IV.

These results confirmed the previous opinions, and samples of water subsequently collected from consumers' taps, fed by lead service pipes which had been in use for a number of years, contained lead in amounts varying from 0.07 to 0.14 parts per 100,000.

On account of the many possible interferences with any particular or chance sample of water, and because it is important to ascertain the amount of lead habitually consumed through the medium of water, an

TABLE III
RESULTS EXPRESSED IN PARTS PER 100,000

		pH.	Dissolved Oxygen.		Lead equivalent to Oxygen Loss.	Lead Found.		Total.
			Original.	Taken up by Lead.		Solution Colloidal.	Suspension.	
SERIES I	Water used in Series I	6.2	0.95	—	—	—	—	—
	24 hours' contact, } Maximum	10.0	0.95	0.70	9.1	2.64	1.98	4.62
	10 days } Minimum	6.5	0.95	0.05	0.7	0.08	0.12	0.20
SERIES II	Water used in Series II	6.6	0.93	—	—	—	—	—
	24 hours' contact, } Maximum	8.0	0.93	0.10	1.3	0.20	0.12	0.32
	6 days } Minimum	6.8	0.93	0.10	1.3	0.16	0.04	0.20
SERIES III	Water used in Series III	5.8	0.90	—	—	—	—	—
	24 hours' contact, } Maximum	7.0	0.90	0.20	2.6	0.22	0.58	0.80
	6 days } Minimum	6.6	0.90	0.05	0.7	0.15	0.09	0.24
SERIES IV	Water used in Series IV	5.2	0.95	—	—	—	—	—
	24 hours' contact, } Maximum	7.0	0.95	0.25	3.2	0.40	0.26	0.66
	6 days } Minimum	6.0	0.95	0.05	0.7	0.12	0.12	0.24
SERIES V	Water used in Series V	5.0	0.95	—	—	—	—	—
	24 hours' contact, } Maximum	6.8	0.95	0.08	1.1	0.28	0.52	0.80
	4 days } Minimum	6.6	0.95	0.05	0.7	0.20	0.33	0.53

TABLE IV
RESULTS EXPRESSED IN PARTS PER 100,000

	No. of Hours' Contact.	pH.		Dissolved Oxygen Loss.	Lead equivalent to the Oxygen Loss.	Total Lead Found (as Pb).
		Original Water.	Sample from Pipe.			
Samples after Standing in Pipe	100	—	9.0	0.28	3.6	0.72
	10	6.5	8.0	0.18	2.3	0.07
	10	6.2	7.5	0.15	1.9	0.22
	10	6.6	6.5	0.28	3.6	0.07
	10	5.8	5.8	0.23	2.9	0.03
	10	5.2	6.8	0.40	5.2	0.25
	10	5.6	6.8	0.37	4.7	0.17
	10	5.6	6.8	0.37	4.7	0.17
Samples after Normal Use during the Day	—	6.2	6.5	0.05	0.7	0.008
	—	6.6	6.5	0.23	2.9	0.043
	—	5.8	5.8	0.23	2.9	0.067
	—	5.2	6.0	0.35	4.5	0.175
	—	5.6	5.6	0.32	4.1	0.110

apparatus has been devised to obtain a reasonably accurate quantitative measure of the total lead content of water supplies.¹

The apparatus consists of a filter, the medium of which is a mixture of chalk and magnesium oxide. It is so designed that, when fitted to a domestic tap, water for drinking and cooking purposes can be drawn through the filter, and water for other domestic uses by-passed. The quantity of water passing through the filter is measured by a recording meter, and when a sufficient quantity has been registered, the filtering medium, which abstracts the lead from the water, is removed. It is then analysed to determine the total amount of lead present, and knowing the volume of water which has passed through the filter, the average lead content of the water can be calculated and an approximation of the daily intake of the consumers thus ascertained.

The following example demonstrates the use of this apparatus.

A water supply which we examined by our standard laboratory method took up less than 0.01 part per 100,000 of lead in twenty-four hours, and from a consideration of this result, together with the analyses, the opinion was expressed that the water would be non-plumbo-solvent, and lead pipes could safely be used. The special filter was installed at the end of a 70 feet length of new $\frac{3}{4}$ inch diameter lead pipe connected to the main of the water supply concerned, and the results obtained are shown below :—

No. of Days of Test.	No. of Gallons of Water Passed.	Total Lead Sulphate found : mgs.	Average Lead Content of the Water : Ph in Parts per 100,000.
(a) 56 . .	35	19.8	0.0083
(b) 45 . .	171	23.4	0.0024

It will be seen from these results that the initial lead content of the water was very small, and fell to a still lower figure as the new pipe became protected from attack. It can be assumed, therefore, that in practice the lead yielded to the water by lead pipes would be infinitesimal, if any, and the results of this experiment fully confirmed the original opinion.

Summarising the position with regard to the examination of water supplies for plumbo-solvency, the points which must receive consideration are the following :—

1. pH value and acidity of the water.
2. Calcium and magnesium bicarbonate content.
3. Organic purity.
4. Variations of the water according to climatic conditions.
5. Treatment applied to the water, if any.

¹ H. Ingleson, M.A., Ph.D. The Determination of Lead in Drinking Water. *The Analyst*, Vol. 63, p. 546, August, 1938.

6. Whether action on lead is transient or continuous, *i.e.*, whether a protective coating is formed in the course of time.

Opinions on single samples should be very guarded. Many waters, particularly from upland and other surface sources, are subject to fluctuations in character according to climatic conditions, etc., and the examples previously given demonstrate the variations and anomalies which arise in testing the action of water on lead.

In carrying out the laboratory test for the action on lead it may be found that the presence of suspended matter in the water inhibits the action, and hence the tests should be carried out on both the raw and the filtered water. The degree of oxygenation of the water at the time of test also has an effect on the result.

It must also be noted that the action of water on lead may be more serious in the hot service than in the cold, and some consumers draw water for drinking purposes, often first thing in the morning, from hot-water taps. We have known lead-poisoning to arise from this cause, but lead pipes are now seldom installed in hot-water services.

When properly-collected samples of water drawn from consumers' taps are found to contain lead, and examination of the supply indicates that the water should have no plumbo-solvent action, very careful investigation of the domestic arrangements should be made. The earthing of electric wires to the water system may be the cause, or the union of dissimilar metals, such as lead and copper, particularly when the water contains appreciable saline constituents (electrolytes). We know of instances in which, owing to these causes, the lead pipes had become so corroded as to crumble into a whitish powder or develop large perforations.

CHAPTER XXII

ESTIMATION OF THE SALINE CONSTITUENTS

It has previously been stated that for many purposes it is desirable to know something of the nature of the saline constituents of a water. Without such analyses as will give this information, the variations in the character of waters from certain sources may not be followed or understood. The complete analysis of waters from definite geological strata gives information of considerable scientific importance, and it is much to be regretted that records of so few analyses of this character are available. In studying the waters derived from the Thanet Sands and the Chalk in various parts of Essex, we had to make hundreds of such analyses, and have gradually improved the processes, until now several analyses can be made in the time formerly occupied in making one. The results are sufficiently accurate for all practical purposes, and certainly as accurate as many analyses carried out by more tedious methods.

For practical purposes it almost invariably suffices to determine the calcium and magnesium, and the carbonates, sulphates, chlorides, nitrates and silica, but the potassium and sodium may be determined where it is desired either to make a more complete analysis or to check the results. On occasions other determinations, such as of Iron, Aluminium, Lead, Iodine, Fluorine, etc., may be necessary.

The estimation of the total solids has already been described in Chapter XVIII.

ESTIMATION OF BASES OR CATIONS

Calcium and Magnesium

These metals are determined in the same portion of water, the magnesium being estimated after the removal of the calcium.

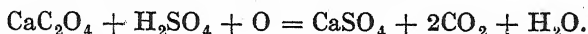
No special apparatus or reagents are required for the calcium estimation.

The volume of water taken is usually 200 c.c., but 100 c.c. will suffice if the hardness of the water exceeds 20 parts per 100,000.

The water is placed in a flask of about 400 c.c. capacity, and, 1 c.c. of dilute hydrochloric acid having been added, it is concentrated by evaporation to about 50 c.c. Whilst this is still hot, a dilute solution of ammonia is added until the liquid has a distinct ammoniacal odour. (If much magnesium is present the addition of ammonia causes turbidity, when more acid must be added, and further ammonia then dropped in until the liquid again becomes alkaline. In exceptional cases, when the water contains appreciable iron, a brown-coloured precipitate

appears when the liquid is made alkaline. The precipitate may be removed by filtration, but this is seldom necessary since the colour is usually insufficient to interfere with the subsequent titration.) Two c.c. of a saturated solution of ammonium oxalate are then added, and the mixture is allowed to stand on the hot plate for one hour. The clear liquid is then passed through a small exhausted filter paper, and the precipitate finally washed on to the paper. The flask is rinsed out three or four times with small quantities (about 5 c.c.) of distilled water, the rinsings being passed through the filter. Finally, the last trace of ammonium oxalate is removed from the paper and precipitate by a fine stream of water from a wash-bottle. The filtrate should not exceed 100 c.c. A little calcium oxalate may adhere to the sides of the flask, but this is of no consequence, as the next step is to wash the precipitate from the filter paper back into this flask. This is done by perforating the filter paper at the apex with a pointed glass rod and washing the precipitate through the perforation. Drop dilute hydrochloric acid on to the filter paper and wash with boiling distilled water. Repeat this thrice. By this means all the calcium oxalate in or on the filter paper is washed into the flask. The liquid in the flask may measure 40 to 50 c.c. Add to it 5 c.c. of dilute sulphuric acid, and heat to 70° C. The whole of the calcium oxalate is dissolved.

Now titrate with N/80 solution of potassium permanganate (1 c.c. = 0.1 mg. O) until a faint pink tint is produced. Note the number of cubic centimetres required. From the amount of oxygen consumed the amount of calcium present is easily calculated.



From this equation it is obvious that 16 parts of oxygen correspond to 40 of calcium; therefore each cubic centimetre of the permanganate solution corresponds to 0.25 mg. of calcium. In other words, the number of cubic centimetres of permanganate solution used, divided by 4, gives the amount of calcium in milligrammes in the quantity of water used.

As previously stated, the magnesium is determined in the filtrate from the calcium oxalate precipitate. The filtrate is allowed to cool, after which it is made up to exactly 100 c.c. The volume of this required for the experiment depends upon the amount of magnesium present. It is best to use a quantity which contains approximately 0.5 mg. magnesium.

To obtain an indication of the quantity to be taken, place a few cubic centimetres of the liquid in a test tube, and add 2 or 3 drops of the solution of ammonium phosphate (see Appendix). If a copious precipitate is produced on shaking, 25 c.c. or less of the solution will be required; with only a faint precipitate, 50 c.c. or more may be used. Alternatively 25 c.c. may be first used, and if this is too much or too little, a second experiment can be made, using the appropriate volume of the filtrate.

The apparatus required includes :—

1. A long, all-glass stirring rod or plunger with one end expanded into a flat disc a little less in diameter than the Nessler cylinder in which the experiment is to be made.

2. A rod with a pair of wires at the end as described on p. 213.

The only other special reagent is a standard solution of magnesium sulphate, each cubic centimetre of which corresponds to 0.25 mg. magnesium. Take the requisite quantity of the filtrate from the calcium precipitate and dilute to 100 c.c. in a Nessler cylinder. Add 2 c.c. of the ammoniacal solution of ammonium phosphate, and immediately commence a rapid up-and-down movement with the plunger. This must be continued for two minutes. The magnesium ammonium phosphate is precipitated in such an exceedingly fine state of division that it shows very little tendency to deposit. Allow to stand a few seconds for any air bubbles present to rise, then immerse in the liquid the turbidity needles, and note the depth at which the thinner one ceases to be definitely recognisable. Repeat this several times and take the average of the readings.

Now make a standard magnesium solution as nearly similar in strength as the above results indicate. With a little experience this is a very simple matter. Treat this standard in the same manner and take a similar series of readings with the turbidity needles.

With waters containing very little calcium and magnesium it may be necessary to concentrate the water before making the determinations.

The following are the results of a determination, the smaller needle used being 1.19 mm. in diameter :—

Estimation was made of the magnesium in a water containing a little calcium salt + 1 mg. of magnesium, as MgSO_4 , in 100 c.c. of water. The calcium having been removed and the filtrate made up to 100 c.c., a portion of 50 c.c. diluted to 100 c.c. was used for the Mg determinations.

	Filtrate.	Standard of .5 mg.
Reading 1	62	64
Reading 2	62	63
Reading 3	63	62
Average	62.3	63

∴ Mg found = 1.01 mg. in 100 c.c. of water.

We have made hundreds of analyses by these methods, and in many cases have also determined the calcium and magnesium gravimetrically. The results have been quite satisfactory, and the time taken by the methods described is only a fraction of that required for a gravimetric analysis.

To ascertain the length of time necessary for the complete precipitation of the calcium by the ammonium oxalate, three experiments were started, and the calcium and magnesium determined in each after

standing one, two, and fourteen hours respectively. The results were as under :—

Mgs. of Ca and Mg taken.		Time of standing.	Mgs. of Ca and Mg found.	
Ca.	Mg.		Ca.	Mg.
9.3	2.0	... 1 hour ...	9.3	1.92
9.3	2.0	... 2 hours ...	9.3	2.04
9.3	2.0	... 14 ,, ...	9.3	1.92

Obviously, therefore, there is no necessity for the liquid to stand more than one hour after the addition of the ammonium oxalate. The amount of ammonium oxalate added, provided it is in excess, is of little consequence. The amount given in the text more than suffices for any water which can be regarded as potable.

Potassium and Sodium

An accurate determination of these metals requires great care. The method frequently adopted of calculating the two from the weight of the mixed chlorides, and the determination of the chlorine therein, is unreliable, since, when such small quantities are being dealt with, an error of even $\frac{1}{10}$ mg. in either experiment seriously affects the result. In the results of analyses submitted to us, whilst the calcium and magnesium determinations have usually corresponded closely, the amounts of potassium and sodium have differed greatly, and this is almost certainly due to the above method of analysis having been adopted.

As the amount of potassium in potable waters is usually very small, it is useless for the purpose of water analysis to try to determine it by this method.

The following process for separating the potassium and sodium salts and estimating the amount of each has withstood a trial extending over several years.

As it is desirable to know the amount of magnesium and of sulphates in the water before commencing the determination of the potassium and sodium, it is better to complete the estimation of the magnesium and of the sulphates whilst the water required for the potassium and sodium estimation is being evaporated.

Take 200 c.c. to 500 c.c. of the water and evaporate in a platinum dish on the water bath to about 50 c.c. Then add sufficient solution of barium chloride (1 c.c. = 2 mg. SO_4 , see Appendix) to precipitate all the sulphates present, and after a little further evaporation add 2.5 c.c. of fresh lime water, made from pure calcium oxide, for each milligramme of Mg contained in the water. Continue the evaporation until only about 10 c.c. remain. Filter through a very small exhausted filter paper into a test tube, and wash the residue in the dish and on the paper with successive small quantities of hot distilled water. Not more than 10 to 15 c.c. need be used. Heat the filtrate to boiling point, add, drop by drop, solution of ammonium carbonate until it produces no further precipitate, then add a droplet of solution of ammonium oxalate. The precipitate at boiling point falls rapidly,

and after standing a quarter of an hour the clear liquid is filtered through a small exhausted paper into a dish and the residue washed with a few cubic centimetres of water. Evaporate the filtrate to dryness on the water bath, and gently ignite to drive off all the ammonium salts. When the dish is cool, moisten the residue with 1 or 2 drops of strong hydrochloric acid and evaporate to dryness. If the water contains more than a trace of nitrates, this process should be twice repeated to convert all the nitrates into chlorides. Dissolve the residue in about 5 c.c. of water, filter as before into a small tared platinum crucible or dish, evaporate to dryness on the water bath, then heat to 120°C . for a few minutes, allow to cool, and weigh. The results give the weight of the potassium and sodium as chlorides.

Dissolve the residue in the smallest possible quantity of water, and add 1 c.c. of the solution of platinic chloride (see Appendix) for every 30 mg. of the mixed chlorides. This ensures the conversion of the whole of the chlorides into double salts. Evaporate until only a moist crystalline residue remains. When cold, pour over it 5 c.c. of pure methylated spirit, allow to stand ten minutes, and pour off the spirit, passing it through a very small filter. Repeat this process again and again; transfer the precipitate to the filter, and continue the addition of spirit until the washings are quite free from colour. The first and second washings may be transferred to the bottle for waste platinum solutions and residues; the subsequent washings should be collected separately, so that the point may easily be recognised at which the washings become colourless. Let the filter dry in a warm place. Dissolve the potassium platinic chloride in a little hot water, washing the filter thoroughly. To the coloured solution, which need not measure more than 10 to 20 c.c., add a very minute quantity of a zinc-copper couple, made as described on p. 233, but using zinc dust, and allow to stand until the liquid is quite free from colour. Pour off the clear liquid into a porcelain dish, wash the residue with successive small quantities of water, add the washings to the liquid, and determine the chlorine therein volumetrically.

The chlorine found multiplied by 0.368 gives the amount of potassium present; multiplied by 0.701 it gives the weight of potassium chloride. The latter, deducted from the weight of the mixed potassium and sodium chlorides, gives the amount of sodium chloride.

The following determinations show the accuracy of this method of determining small quantities of potassium. The salt used was potassium nitrate :—

Potassium taken. gm.	Potassium found. gm.
0.0056	0.0053
0.0056	0.0058
0.0056 (with a little sodium salt)	0.0053
0.0056 " " "	0.0052

In the following determinations a mixture of potassium nitrate and sodium carbonate was used :—

Taken.		Found.	
K. gm.	Na. gm.	K. gm.	Na. gm.
0.0056	0.0476	0.0056	0.0469
0.0014	0.0030 (+ MgSO ₄ + CaCl ₂)	0.0015	0.0029
0.0112	0.0306 " "	0.0106	0.0308
0.01395	0.0390 " "	0.01375	0.0388

The amount of potassium salts found in potable waters is usually so small that it is rarely worth the trouble of determining. If upon applying the flame test the potassium coloration is very evanescent, and if the total saline constituents, assuming potassium to be absent, closely approach the total solids obtained by weighing, it is not necessary for any practical purpose to attempt the estimation of the potassium.

The quantities found in waters from different sources will be found in later Tables of analyses. Possibly it is not without significance that most potassium is found in water containing an excessive amount of nitrates.

The following Table is taken from records of the analyses of a series of samples of water taken at monthly intervals from a well in the Chalk which was affected by the infiltration of sea water, and which, therefore, contained considerable amounts of magnesium salts. The amount of water used was invariably 200 c.c., and the first two columns give the actual results obtained, from which those in the second two columns are calculated per 100 c.c.

KCl + NaCl obtained	Cl in platinic salt as determined	K calculated	Na per 100 c.c.
Mlgr.	Mlgr.	Mlgr.	Mlgr.
74.0	5.5	1.0	13.8
80.5	6.5	1.2	14.95
63.7	5.4	1.0	11.3
31.0	3.6	0.65	5.6
80.6	7.6	1.4	14.8
70.5	5.7	1.05	13.1
64.5	4.9	0.9	12.0
68.0	5.5	1.0	12.6
62.5	4.7	0.86	11.2

Alumina (Al₂O₃)

The amount of alumina present in potable waters is usually negligible. If, however, the test described on p. 255 reveals its presence, or for some other reason an accurate estimation is required, then a gravimetric determination can be made on the filtrate obtained from the gravimetric determination of silica given on p. 303. This filtrate is evaporated to a low bulk (about 20 c.c.), a drop of nitric acid added, and the mixture boiled to oxidise any trace of iron present. Add a little ammonium chloride solution to prevent the precipitation of magnesia, and a very slight excess of ammonia. On again boiling, the alumina is precipitated,

devoid of colour if pure, but of a brown tint if iron is present. The precipitate is transferred to a small filter, thoroughly washed, dried, and finally ignited in a tared crucible. The heating should be continued over the blowpipe for about five minutes. The weight of the residue will be that of the alumina plus any ferric oxide present. As the iron in the water will have been already determined, the amount of ferric oxide present can be calculated and deducted; the remainder will represent the amount of alumina in the quantity of water originally evaporated.

ESTIMATION OF ACIDS OR ANIONS

Carbonates

The following process for the estimation of CO_3 necessitates the use of a tall colourless glass cylinder of 250 c.c. capacity, a sufficiently long agitating rod with a disc at the end, a standard solution of sulphuric acid (1 c.c. = 2 mg. CO_3), and a solution of methyl orange (see Appendix). This indicator varies much in delicacy, and a sample should be obtained giving a decided reaction with 0.1 c.c. of the standard acid in 200 c.c. of distilled water free from CO_2 and with pH 7. The amount of indicator used is also a matter of importance. With too much the end reaction is obscured; with too little the reaction is not sufficiently definite. Before applying the process, a few experiments should be made in order to acquire the requisite skill in observing the change from yellow to orange. At first this is a little difficult, but soon it becomes comparatively easy, and the results given below show that they are concordant and reliable.

A turbid water must be clarified by filtration before carrying out this determination.

Into the cylinder introduce 200 c.c. of the water and 1 c.c. of methyl orange solution. Then run in the acid from a burette until an orange tint appears, and note the amount of acid used. Finally, pour in more of the water until the orange tint is just discharged. The readings of the amount of water used are taken.

The following are the details of an experiment :—

200 c.c. of the water required 6.2 c.c. of acid to produce an orange colour, and 8 c.c. more of the water restored the yellow tint.

$$\frac{200 + 208}{2} \text{ c.c. water} = 2 \times 6.2 = 12.4 \text{ mg. } \text{CO}_3.$$

\therefore 100 c.c. water contained 6.07 mg. CO_3 .

The water used was distilled water containing 6.0 mg. CO_3 , as sodium carbonate, in 100 c.c.

In a series of experiments in which only the first reading was taken the results were uniformly slightly in excess, and led to the adoption

of the method described, in which the mean of two observations is taken. Using this process, the following results were obtained :—

CO ₂ mg. per 100 c.c.		CO ₂ found mg. per 100 c.c.
9.6	in distilled water	9.5
9.6	" "	9.6
6.9	" "	6.96
2.8	" "	2.8
2.8	" " + CaCl ₂ + MgSO ₄	2.7
5.6	" "	5.52
2.9	" "	2.96
40.4	" "	40.2
9.6	" "	9.5
5.9	" " + Na ₂ SO ₄	5.84
2.1	" "	2.16
5.1	as CaCO ₃	5.2

The above results show the reliability of this method. The following modification may be preferred by those who experience difficulty in defining the end reactions :—

Take 200 c.c. of the water, add the methyl orange, and run in the acid until an orange tint is suspected. Now divide the whole into two portions in tall Nessler glasses of exactly the same type and tint of glass, and into one add more acid, drop by drop, until the orange-red tint is distinct, pH 4.5.

Experiments which we have made, using benzene-azo- α -naphthylamine (pH 3.7 to 5) as the indicator, lead us to think that the end point (a faint but distinct red) is more easily observed with this reagent than with methyl orange and that it may be more generally acceptable.

Sulphates (SO₄)

The SO₄ may be determined rapidly and usually with reasonable accuracy by the following method :—

Turbidimetric Method. This requires the use of Nessler cylinders and a plunging rod with expanded end as described on p. 296, dilute hydrochloric acid, 10 per cent. solution of barium chloride, and a standard solution of sulphuric acid, the same as is used in the CO₂ determination (1 c.c. = 3.2 mg. SO₄).

The water to be examined should not contain more than 5 mg. SO₄ in 100 c.c., otherwise, it should be diluted until the dilution contains between 3 and 4 mg. in that quantity.

Take 100 c.c. of distilled water in a Nessler cylinder, add 1 c.c. of the standard solution of sulphuric acid, 2 c.c. of dilute hydrochloric acid, and 1 c.c. of the barium chloride solution. Agitate vigorously and continuously for two minutes. Set aside.

Next take 100 c.c. of the water, or a known dilution, add the hydrochloric acid and barium chloride, and agitate as before.

Using the turbidimetric rod described on p. 213, ascertain the respective depths of the columns of the turbid mixtures required to obliterate the wire, or to leave it just recognisable. If there is any con-

siderable difference, the water must be diluted or concentrated until a sufficiently close approximation is obtained. The average of a number of readings should be taken.

If a = the average depth in mm. of the standard,

b = the average depth in mm. of the water,

then the amount of SO_4 in 100 c.c. of the water (or dilution) used is

$$3.2 \times \frac{a}{b} \text{ mg.}$$

For example, a solution of a sulphate known to contain 3.8 mg. SO_4 in 100 c.c. was compared with the standard containing 3.2 mg. SO_4 per 100 c.c. The readings were as under :—

Standard.		Water.
31	...	25.5 reading to obliteration of wire.
28	...	24.0 reading to bare discernment of wire.
Mean 30	...	25.0

$$\begin{aligned} \therefore \text{SO}_4 \text{ in the solution} &= 3.2 \times \frac{30}{25} \text{ mg.} \\ &= 3.8 \text{ mg.} \end{aligned}$$

The following experiments also show the accuracy of the process :—

SO ₄ calculated in 100 c.c. mg.		SO ₄ found. mg.	SO ₄ calculated in 100 c.c. mg.		SO ₄ found. mg.
0.95	.	0.91	3.0	.	2.9
1.24	.	1.15	6.6	.	6.6
1.52	.	1.44	10.5	.	10.4
2.0	.	2.07			

For waters containing small quantities of sulphates this very rapid process leaves nothing to be desired. Any slight error in the determination, however, is increased in calculating the results in proportion to the dilution; hence, when the water to be examined contains over 20 mg. SO_4 per 100 c.c., as can be readily ascertained by a rough turbidimetric experiment, it is best to make a gravimetric estimation.

Gravimetric Method. To determine the sulphate gravimetrically it is precipitated as barium sulphate (BaSO_4). Sufficient water is taken to give a precipitate of 50 to 100 mg. of barium sulphate (20 mg. $\text{SO}_4 \equiv 49 \text{ mg. BaSO}_4$). The water is made just acid with dilute hydrochloric acid and evaporated to between 50 and 100 c.c. A boiling solution of barium chloride, 1 c.c. $\equiv 2.0 \text{ mg. SO}_4$ (see Appendix), is next added to the gently boiling sample and the ebullition continued for five to ten minutes, this precaution ensuring a coarse filterable precipitate of sulphate. The amount of barium chloride added must be only slightly in excess. This amount may be determined from a rough turbidimetric estimation or by adding, when precipitation is judged complete, a few drops of the barium chloride solution to the filtered or clear decanted liquid. The precipitate is filtered off and washed with boiling water until the filtrate gives no turbidity with silver nitrate solution. Precipitate and filter paper are very gently ignited, the paper being

first carefully charred. A small portion of the sulphate may be reduced to sulphide during ignition, and it is reconverted to sulphate by moistening with a few drops of dilute sulphuric acid, gently heating to drive off the acid, and then strongly re-ignited (1 mg. of $\text{BaSO}_4 \equiv 0.411$ mg. of SO_4).

Silica (Si_2O) and Silicates

For the gravimetric determination of silica a relatively large volume of water must be taken in order to obtain a weighable residue. A measured volume of $\frac{1}{2}$ or 1 litre of the water is acidified with hydrochloric acid and evaporated to dryness in a platinum basin on the water bath.

The residue is dried at 180°C . for half an hour, cooled, moistened with hydrochloric acid and the basin returned to the water bath. The acid is then diluted with hot water and the insoluble matter filtered off on a small filter paper, washed with hot distilled water acidified with hydrochloric acid until free from sulphates, ignited in a tared platinum crucible and then weighed.

The insoluble residue usually consists entirely of silica. Its purity may be tested after weighing by adding 2 or 3 drops of concentrated sulphuric acid and a little hydrofluoric acid, volatilising the acids, igniting and again weighing. The loss in weight gives the true silica, SiO_2 . Any appreciable non-volatile residue should be further examined.

The following colorimetric method of Diénert and Wandenbulcke (*Comp. rend.*, 1923) is capable of detecting minute amounts of silica and may be applied to the water direct without concentration.

To 50 ml. of the water in a Nessler glass, 2 ml. of 10 per cent. ammonium molybdate and 4 drops of sulphuric acid (1:1) are added, mixed and allowed to stand. After ten minutes the yellow colour produced is compared with standards made by diluting a solution containing 25.6 mg. of vacuum-dried picric acid in 100 ml., 1 ml. of which added to 50 ml. of water represents 1 mg. of SiO_2 in 100 ml. of water.

The test is capable of detecting 0.05 mg. of silica in 50 ml. of water.

Waters containing more than 3 parts per 100,000 should be previously diluted with distilled water, free from silica. (A pure distilled water kept in a white glass bottle may take up 0.3 mg. SiO_2 per 100 ml. in a month.)

This method does not measure suspended or colloidal silica.

To determine the total silica, 50 ml. of the water to which 0.2 gm. of sodium bicarbonate has been added should be heated in a platinum dish for one hour on the water bath, cooled, neutralised by the addition of 2.4 ml. of N sulphuric acid, made up to 50 ml. and the colour test then applied as above.

Phosphates in normal amounts do not interfere, but hydrogen sulphide must be removed. (The picric acid used for the colour standards must be vacuum-dried. The weight given above is that recommended by King and Lucas, *J.A.C.S.*, 1928, 50.)

The intensity of the yellow colour due to silica is influenced by the concentration of the sulphuric acid present, too little or too much preventing the development of the maximum colour.

If the test is carried out at 25° C., adding to 50 ml. of the water 2 ml. of 10 per cent. ammonium molybdate solution and 4 ml. of 2N sulphuric acid, the maximum colour is developed in ten minutes, and it is under these conditions that the colour glasses supplied with the B. D. H. Lovibond Nessleriser (silica test) have been standardised.

The American Public Health Association (Standard Methods) adopts as a standard colour that of a solution of 0.530 gm. of anhydrous potassium chromate in 100 ml. of water (1 ml. of this solution is equivalent to 1 mg. SiO_2) and details the following method as being applicable to boiler waters containing phosphates (see Appendix, No. 35A) :—

“To 110 ml. of boiler water add 50 ml. of buffer solution, 2 ml. of calcium chloride solution, and stir vigorously. If phosphates are present, a flocculent precipitate of calcium phosphate forms which settles rapidly. Allow the solution to stand for approximately two hours (in any event, at least one hour), with occasional stirring, and then filter. To 50 ml. of the filtrate add 2 ml. of ammonium molybdate solution and 1 ml. of the 3 to 2 hydrochloric acid solution. After allowing the solution to stand for ten to fifteen minutes, compare the silica color intensity with the potassium chromate silica standards. Multiply the apparent silica concentration by the dilution factor, which is 1.56. The analysis should be carried out periodically on 110 ml. of silica-free distilled water to determine the silica content of the reagents, and this blank should be subtracted from subsequent determinations.”

In an alkaline water the SiO_2 may be present as Na_4SiO_4 , in which case 1 part of SiO_2 represents 3.05 parts of Na_4SiO_4 ; in a neutral solution the silicate may be Na_2SiO_3 , when 1 part $\text{SiO}_2 = 2.03$ parts of silicate; in an acid solution the silicate present may be $\text{Na}_2\text{Si}_2\text{O}_5$, in which case 1 part of $\text{SiO}_2 = 1.5$ of the silicate.

Where a water contains free carbonic acid, $\text{Na}_2\text{Si}_2\text{O}_5$ or CaSi_2O_5 is the most probable constituent, and the study of analyses of numerous waters shows that this is most likely, since the other silicates would in nearly all cases make the total solids by addition more than the total solids by direct estimation.

Expression of Results of Analyses

When a complete analysis has been made as described, the analyst may simply give the results obtained or combine the ions to represent the probable saline constituents of the water. In the present state of our knowledge there are objections to both methods. Both are based on theories which are far from meeting with general acceptance. We prefer to give the probable combinations, by which are meant the salts most probably taken up by and dissolved in the water. This differs very little from the usual method of combining the ions in the order of insolubility of the salts formed by their combination.

A Table in the Appendix contains a list of salts which may enter into solution in natural waters, in the order of their insolubility, as given by Bunsen in his "Instruction für die Ausführung der vom Grossherzog. Bad. Ministerium des Innern angeordneten chemischen Untersuchung der Badischen Mineralwasser." The number of such salts found in ordinary potable waters is small, and we determine them in the following order :—

- | | | | |
|-------------------------------|-------------------------------|------------------------------|--|
| 1. CaCO_3 | 6. MgSO_4 | 10. Na_2SO_4 | 14. KCl |
| 2. CaSO_4 | 7. MgCl_2 | 11. NaCl | 15. KNO_3 |
| 3. CaCl_2 | 8. $\text{Mg}(\text{NO}_3)_2$ | 12. NaNO_3 | 16. K_2CO_3 |
| 4. $\text{Ca}(\text{NO}_3)_2$ | 9. Na_2CO_3 | 13. K_2SO_4 | 17. $\text{Na}_2\text{Si}_2\text{O}_5$ |
| 5. MgCO_3 | | | |

This is not exactly in the order of insolubility, but in practice it works out more in accordance with the order of probability, and its simplicity is obvious. As long as the actual determinations are given, the combinations in which they are expressed is less important.

Factors for use in calculating the saline constituents are given on p. 802 in the Appendix.

The following examples will illustrate the mode of calculating the different constituents, and of recording the results :—

WATER FROM WELL IN THE CHALK IN SOUTH ESSEX

Ions in parts per 100,000

Cations.				Anions.			
Ca	.	.	7.5	CO_3	.	.	12.0
Mg	.	.	1.2	SO_4	.	.	3.4
Na	.	.	1.65	Cl	.	.	3.0
K	.	.	0.55	NO_3	.	.	0.13

The 7.5 of Ca would combine with $7.5 \times 1.5 = 11.25 \text{ CO}_3$, forming 18.75 CaCO_3 .

The remaining CO_3 , $12 - 11.25 = 0.75$, would combine with

$$\frac{0.75}{2.46} = 0.3 \text{ Mg, forming } 1.05 \text{ MgCO}_3.$$

The remainder of the Mg, $1.2 - 0.3 = 0.9$, would combine with

$$0.9 \times 3.94 = 3.55 \text{ SO}_4, \text{ forming } 4.45 \text{ MgSO}_4.$$

Or 3.4 SO_4 would combine with

$$\frac{3.4}{3.94} \text{ Mg} = 0.86, \text{ forming } 4.26 \text{ MgSO}_4.$$

The latter leaves 0.04 Mg uncombined, whilst the former shows that, to combine with the 0.9 Mg, the SO_4 required is 0.146 more than the SO_4 found in the water. With such trifling differences take the mean of the two determinations :—

$$(4.45 + 4.26) \div 2 = 4.35.$$

306 ESTIMATION OF THE SALINE CONSTITUENTS

This brings the determination within 0.1 mg. per 100 c.c. of either result.

The Na would combine with $1.65 \times 1.54 = 2.54$ Cl, forming 4.19 NaCl.

The K would combine with the remaining Cl and the NO_3 .

The water contained also 0.8 mg. Fe_2O_3 in suspension.

The total solids determined after evaporation and drying at 180°C ., weighed 31.7 mg., leaving 1.45 for silica, trace of organic matter, and errors. The silica was not determined in this case.

The results are duly entered as shown on the following form :—

SALINE CONSTITUENTS OF A SAMPLE OF WATER FROM CHALK WELL IN SOUTH ESSEX

Expressed in parts per 100,000.

Ca 7.5	Mg 1.2	Na 1.65	K .55	CO_2 12.0	SO_4 3.4	Cl 3.0	NO_3 .13	Probable combinations	
7.5	—	—	—	11.25	—	—	—	Calcium carbonate .	18.75
—	.3	—	—	.75	—	—	—	Magnesium carbonate .	1.05
—	.9	—	—	—	3.45	—	—	„ sulphate .	4.35
—	—	1.65	—	—	—	2.55	—	Sodium chloride .	4.20
—	—	—	.5	—	—	.45	—	Potassium chloride .	.95
—	—	—	.05	—	—	—	.10	„ nitrate .	.15
—	—	—	—	—	—	—	—	Ferric oxide .	.80
—	—	—	—	—	—	—	—	Traces silica, &c. .	1.45
Total solid constituents dried at 180°C									31.7

In the analyses given above all the basic constituents have been used in calculating the combinations and 0.03 part per 100,000 of nitrate (NO_3) has been ignored. This quantity is, of course, within the general experimental errors of the analysis. In most natural waters it will be found that, within the limits of experimental error, the basic radicals are equivalent to the acidic constituents when the silica is left uncombined.

It is assumed in these cases that the silica exists in a free state. The analysis of an alkaline water, say a freshly lime-softened water, may show that the whole or part of the silica must be combined as one or other of the sodium silicates before the basic radicals are all used in the formation of probable combinations.

THE GASES DISSOLVED IN WATER

(a) Estimation of the Carbon Dioxide

The method recommended was described by Trillick, and gives very satisfactory results. Moreover, it requires no special apparatus

and no special reagents. It depends on the fact that, when a solution of barium hydroxide is added to the water, the free and the so-called semi-combined CO_2 combine with the barium hydroxide, insoluble barium carbonate being precipitated. Calcium carbonate, being practically insoluble in water, is precipitated when the CO_2 is removed, but the magnesium carbonate is converted into magnesium hydroxide, and the other magnesium salts are also decomposed in a similar manner. Sodium carbonate also causes a precipitate with the barium hydroxide, but as an equivalent of sodium hydroxide is formed this does not interfere with the reaction. From the loss of alkalinity it is only necessary to deduct that due to the presence of magnesium salts, and the remainder represents, and permits calculation of, the free and semi-combined CO_2 in the amount of water examined. It is assumed, therefore, that the Mg will have been determined.

The reagents required are a standard solution of sulphuric acid (1 c.c. = 2 mg. CO_3), a freshly-titrated baryta water, and a solution of barium chloride, 1 c.c. = 2 mg. SO_4 (see Appendix).

Into a flask capable of holding a little over 250 c.c., place 200 c.c. of the water to be examined, add 10 c.c. of the barium chloride solution, gently rotate the flask, and after a few seconds add 40 c.c. of the baryta water. Close with a well-fitting stopper, and gently agitate until the mixture is uniform. Set aside all night or until the supernatant liquid is quite clear.

Remove with a pipette 100 c.c. of the clear liquid, add a little dilute phenolphthalein, and titrate with the standard acid. The amount of acid which would be required to neutralise the whole of the liquid is then calculated, and this, deducted from the amount required to neutralise 40 c.c. of the baryta water used, gives the loss due to the carbon dioxide and magnesium salts.

1 c.c. of the standard acid = 2 mg. CO_3 = 1.47 mg. CO_2 .

1 mg. Mg corresponds to 1.83 mg. CO_2 .

Let x = the amount of free and semi-combined CO_2 in 100 c.c. of the water ;

a = the amount of Mg in 100 c.c. of the water ;

b = the number of cubic centimetres of acid required to neutralise 40 c.c. of the baryta water ;

c = the number of cubic centimetres required to neutralise the excess of baryta in the 200 c.c. of water,

$$\text{then} \quad 1.47 \frac{b - c}{2} = x + 1.83a,$$

$$\text{whence} \quad x = 0.735 (b - c) - 1.83a.$$

The following is an example of such an analysis :—

The baryta water employed was of such strength that 40 c.c. required 98 c.c. of the standard sulphuric acid for neutralisation. 200 c.c. of the water were taken and 100 c.c. of the clear supernatant mixture removed for titration. This required 30.4 c.c. of acid to neutralise the excess

of barium hydroxide. The water plus reagents amounting to 250 c.c., and 100 c.c. being taken for the analysis, the excess of alkali in the 100 c.c. multiplied by 2.5 gives the excess in the 200 c.c. of the water used. This gives $30.4 \times 2.5 = 76$ c.c. as the amount of acid necessary to neutralise the total excess of alkali.

The free carbonic acid can be estimated by either of the following methods with sufficient accuracy for most practical purposes :—

1. To 100 c.c. of the water in a Nessler cylinder add 1 c.c. of 0.2 per cent. phenolphthalein solution (see Appendix), and drop in from a burette N/20 solution of sodium carbonate until the pink colour becomes permanent. The tube should stand on a white tile, and the best form of agitator is a glass rod with a round, flattened and expanded end, fitting easily in the tube. By raising and lowering the rod gently, instantaneous admixture is ensured.

The cylinder should be a long one, capable of holding 200 c.c., to avoid as far as possible any current of air over the surface of the water, and the pink tint should be just discernible at the end of three minutes.

2. A standard N/20 soda solution is made by dissolving 2.6525 gms. of pure sodium carbonate and 2.5 gms. of phenolphthalein in boiled distilled water and making up to 1 litre. 100 c.c. of water are titrated with this solution to a permanent pink colour. A zero-point correction of 0.5 c.c. is deducted from the number of cubic centimetres used, and the remainder multiplied by 1.22 (instead of the theoretical 1.1) in order to calculate the milligrams of free CO_2 in 100 c.c. of the water. The accuracy of the results is not affected by the alkalinity (bicarbonate) of the water (*Analyst*, 1919, 44, 245).

The free CO_2 in any water varies somewhat rapidly. When it amounts to 3 or more milligrams per 100 c.c., a marked loss may take place in an hour in a bottle incompletely filled. If it is desired to know the amount of free CO_2 present in a water as it flows into a tank or well, a special apparatus should be employed for collecting the sample, as described on p. 193, and the determination should be made immediately.

(b) Estimation of the Dissolved Oxygen

The method most generally used is that of Winkler, which is described in Chapter XIX, p. 265. The preliminary treatment with permanganate is usually unnecessary for potable waters. For field work, and when there is a fairly large amount of oxygen in solution, the Miller method may be used. Although requiring experience, this method has the advantage of being simple and rapid, and is sufficiently accurate for most practical purposes. Winkler's method should, however, be employed in cases of importance and when accuracy is required.

Miller's ¹ method is described as follows :—

“To 50 c.c. of the water contained in a 100 c.c. Nessler glass are added 5 c.c. of alkaline tartrate such as is used for Fehling's solution, and 1 drop of pheno-safranine solution (1 grm. in 2,000 c.c. of water);

¹ *Journ. Soc. Chem. Ind.*, 1914, No. 4, Vol. 33, p. 185.

then, from a 10 c.c. graduated pipette, a solution of ferrous sulphate (0.22 grm. of pure FeSO_4 and 1 c.c. of concentrated H_2SO_4 in 100 c.c.) is run in just below the surface of the liquid, stirring gently with the pipette until the colour is discharged, looking through the cylinder horizontally. The ferrous sulphate is added 1 c.c. at a time until the colour begins to fade, then in quantities of 0.5 c.c. to the end. There is a slight coloration at the surface of the liquid, but if the stirring is not too vigorous this does not interfere. The outlet hole of the pipette should not be more than 1 mm. in diameter, to minimise diffusion.

"The pipette reading gives the cubic centimetres of oxygen per litre. Theoretically, 1 c.c. of ferrous sulphate of the above strength does not equal 1 c.c. of oxygen per litre, working on 50 c.c. of sample (0.25 per cent. FeSO_4 is the theoretical strength); but under the conditions stated I have found that the above strength gives correct results.

"Each experimenter should standardise his ferrous sulphate against water of known oxygen content, say, distilled water shaken with air until saturated, taking the temperature and referring to Roscoe and Lunt's table (Sutton's 'Volumetric Analysis,' 6th Edition, p. 260) for the amount of dissolved oxygen present."

A saturated water at ordinary temperatures contains about 1 mg. oxygen per 100 c.c., but waters in which vegetation is active are often supersaturated, whilst very impure waters often contain much smaller quantities.

(c) Estimation of the Total Gases

The water to be used for the estimation of the dissolved gases should be collected in boiling flasks of from $\frac{1}{2}$ to 1 litre capacity, using the arrangement described on p. 193. Before withdrawing the flask, a perforated and plugged rubber stopper should be inserted.

The method for determining the volume of gases dissolved in water is illustrated in Fig. 22; *a* is the flask containing the water, *b* a piece of narrow-bore tubing, connected by a short length of stout rubber tubing carrying a pinchcock, with the tubulure *b'* projecting from the glass collecting vessel *c*. The second tubulure *d'* is similarly connected by means of a rubber tube, carrying a pinchcock, with a length of thermometer tubing *d*, by means of which gas collected in *c* can be transferred to the eudiometer, or absorption tube, *g*. The open vessel, *e*, containing mercury, is connected with *c* by a length of stout rubber tubing.

When a determination is to be made, the flask filled with water is placed upon the stand, the vessel *e* lowered and filled with mercury. The pinchcocks on *b b'* and *d d'* are released, and *e* raised gradually until *c* and the tubes connected therewith are filled with mercury, care being taken to leave no air bubbles in the rubber tubing under the pinchcocks. The pinchcocks are then closed, and *e* lowered as far as possible and left in this position for some time, when, if no air bubbles have made their appearance, the experiment can be proceeded

with. The free end of *b* is now inserted into the orifice in the stopper of the flask containing the water (care having been taken previously to replace any air or water in the cavity by mercury, and to see that the tube *b* is quite full of that metal), and gently pushed down so as to force the plug into the bottle, and until the end of the tube can just be seen below the stopper.

In now releasing the clamp upon *b b'*, lowering *e* and applying heat to the flask, the heat and diminished pressure cause the gas to be readily given off, and the water will boil at a temperature below 100° C. depending, of course, upon the difference between the levels of the mercury in *c* and *e*. The expansion of the water causes a portion

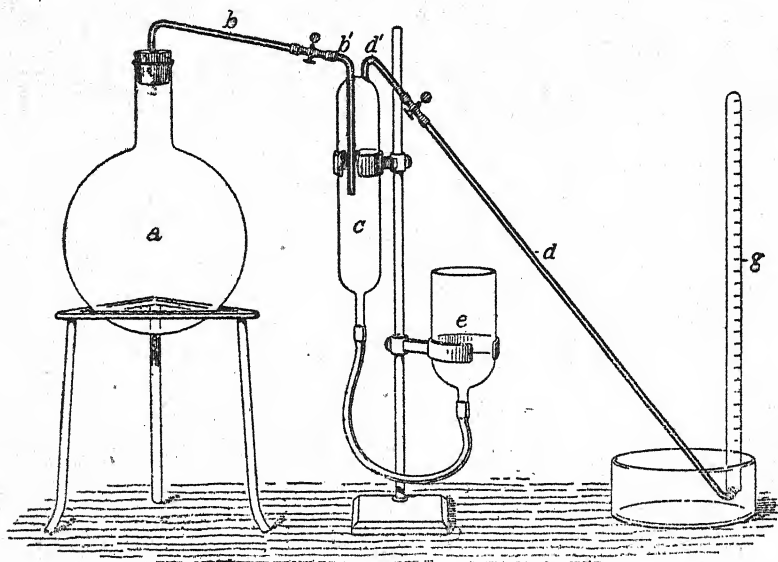


FIG. 22.

to pass into *c*, above which the evolved gas collects, and when the latter nearly half fills the tube, *e* is raised after opening the pinchcock on *d d'*, and most of the gas is thus forced into the absorption tube. This process can be repeated as often as necessary, care being taken not to force any mercury into the water flask, nor any water into the tube *d d'*, and to keep the end of the tube *b'* always under the surface of the fluid in *c*. Finally, by keeping *e* raised until the water is nearly at 100° C., and then lowering, the water in *c* may be made to boil and give up almost the last trace of gas. On again raising *e*, etc., the whole of the evolved gas is collected in *g*, saturated with moisture, but, due precaution having been taken, without any trace of water on the surface of the mercury.

The capacity of *c* may vary according to the volume of gaseous constituents of the water, but will depend chiefly upon the quantity of water used, as when much gas is present it can readily be transferred

from time to time into g. For flasks of from $\frac{1}{2}$ to 1 litre capacity, *c* should be capable of holding at least 100 c.c.

The gas collected in the graduated tube must be measured, and reduced to N.T.P. It almost invariably consists of oxygen, nitrogen (including argon, etc.), and carbon dioxide. If desired, the mixed gases can be submitted to analysis.

(d) Estimation of the Nitrogen

The free and semi-combined carbon dioxide and the free oxygen having been determined, and the total volume of gas liberated by boiling ascertained, the difference between the sum of the two former and of the latter may be taken as the amount of nitrogen present.

For example, in 100 c.c. of a given sample of water the free and semi-combined carbon dioxide amounted to 6.3 c.c. at N.T.P., and the oxygen present was 0.5 c.c. The total amount of gas evolved from 490 c.c. of the water was 54.2 c.c. measured at 14° C. The barometer reading was 758 mm., and the mercury in the measuring tube was 175 mm. above the level of that in the trough. The tension of aqueous vapour at 14° C. being 11.9 mm., the pressure of the gas was 758 — 175 — 11.9 = 571.1 mm.

Corrected to N.T.P., the volume of the gas evolved from 100 c.c. of water would be :—

$$54.2 \times \frac{571.1}{760} \times \frac{273}{273 + 14} \times \frac{100}{490} = 7.9 \text{ c.c.}$$

The water, therefore, contained :—

Oxygen	.	.	.	.	.	.	0.5 c.c.
Nitrogen	.	.	.	.	.	.	1.1 „
Carbon dioxide	.	.	.	.	.	.	6.3 „
							<hr/>
							7.9 „

The following are a few examples of actual determinations :—

GASEOUS CONSTITUENTS OF WATERS

By volume in 100 c.c.

—	Fresh rain-water.	Limestone spring-water, Buxton.	A pure river-water.	A sewage-polluted river-water.
	c.c.	c.c.	c.c.	c.c.
Carbon dioxide . . .	0.14	1.46	3.00	5.60
Oxygen . . .	0.64	0.00	0.75	0.025
Nitrogen . . .	1.80	2.21	1.50	1.51
	<hr/>			
	2.08	3.67	5.25	7.135

Whilst the free carbon dioxide and oxygen are still frequently determined, the nitrogen is rarely estimated. At one time it was suggested that the ratio of the nitrogen to the oxygen was an index of the quality of the water; pure water containing at least half as much oxygen as nitrogen, impure water containing a smaller proportion of oxygen. This may be true of most river waters, but there are certainly numerous exceptions among other waters, and consequently the determinations are rarely made.

The gases evolved from water on boiling, and collected in the way above described, may be submitted to any of the ordinary processes of gas analysis for the determination of the constituents. When water is boiled, half the carbon dioxide in the bicarbonates is evolved, and, unless the total carbon dioxide found in the gas collected exceeds the amount which would be given off by the bicarbonates, the water cannot be said to contain any free carbonic acid.

Anyone interested in the determination of the gases dissolved in water should consult Dr. Traver's work, "The Experimental Study of Gases," which contains a description of the late Lord Rayleigh's apparatus for extracting gases from water.

CHAPTER XXIII

SPECIAL EXAMINATIONS

1. Determination of Iodine and Bromine, Iodides and Iodates, Bromides and Bromates

WHEN examining waters suspected to be contaminated with sea water, it is often desirable to ascertain whether bromides can be detected, as these are always present in sea water in easily detectable quantity. When examining a series of Essex deep well waters, which contain sea water and have been altered by filtration through zeolitic sands, there was very little difficulty in discovering bromides in the saline residues, and in obtaining indications of the presence of other compounds of bromine and iodine. Attempts to estimate the quantities present were more or less failures, as no process described gave concordant results. The working out of a process necessitated prolonged investigation, and it is doubtful whether all the factors essential to secure accuracy have been discovered. The process to be described was worked out in stages, using at first simple aqueous solutions of iodides, iodates, bromides, or bromates. Then various salts were added, such as sodium chloride, etc., to ascertain the effect of their presence; then mixtures of iodides, iodates, etc., were tried, with and without admixture of such salts as occur in potable waters.

The first process fully worked out was found to require modification when tried with the natural brominated water of Woodhall Spa, but, using waters of this character, results are now obtainable which appear to be reliable if all the details are carefully carried out, and experience has been gained by examining a few artificially prepared waters containing known quantities of iodine and bromine compounds. The reagents required are :—

1. Freshly prepared chlorine water made from washed chlorine gas, free from any trace of acid, and of such strength that 1 c.c. will liberate approximately 0.5 mg. of iodine.
2. Solution of sodium thiosulphate of such strength that 1 c.c. corresponds approximately to 0.5 mg. of iodine.
3. Purified petrol. Commercial petrol is treated with bromine until a red colour remains distinct at the end of twenty-four hours. It is then washed with dilute caustic soda solution until perfectly colourless, and then with successive quantities of distilled water until the washings are neutral and give no opalescence with silver nitrate.

Apparatus. 50 c.c. and 100 c.c. stoppered cylinders, separating funnels, etc.

Process. To the water to be evaporated, a drop of phenolphthalein

solution is added, and sufficient pure sodium carbonate to give an alkaline reaction. Evaporate in a Jena glass flask, adding sodium carbonate from time to time to maintain a distinct pink colour. When the volume is reduced to about 100 c.c., filter off the insoluble residue, wash this with distilled water, and again evaporate until crystals begin to form. Cool, and dissolve any deposited crystals in a little water. Add a drop of very sensitive methyl orange and carefully neutralise with N/25 hydrochloric acid. The liquid may have a perceptible orange tint, but if 0.1 c.c. of the acid is added in excess, and iodates and iodides are present, these will react and lead to a slight error. On the other hand, if any carbonate remains in the liquid, both the iodide and bromide determinations will be affected.

Whilst the evaporation is taking place, the reagents may be standardised—the thiosulphate against N/25 iodine solution, and the chlorine water against solutions of bromide and of iodide in distilled water, using known quantities of iodide and bromide, and titrating in the manner described below.

Divide the evaporated solution into three equal parts. Use one for the determination of the iodides and bromides, a second for the iodates and bromates, and the third for repeating either. •

Estimation of the Iodide. To one portion of the concentrated water in a narrow stoppered cylinder or separating funnel, add 3 to 4 c.c. of purified petrol, and introduce the chlorine water, drop by drop at first, with constant agitation. (More than 0.5 c.c. must never be added at a time.) After each addition, remove the coloured petrol, transferring it to another cylinder. Continue this until, with the last drop of chlorine water added, the red colour due to the methyl orange suddenly disappears. This indicates the point at which all the iodide has been decomposed. Wash the removed petrol with a few c.c. of distilled water and transfer the washings to the aqueous solution. Continue the addition of chlorine water to the iodine solution in the petrol until all the colour is discharged. Vigorous agitation and time are required towards the end of the reaction. From the amount of chlorine water used, the quantity of iodine present as iodide is calculated.

Estimation of the Bromide. About 5 c.c. of petrol are now added to the aqueous solution and the addition of chlorine water continued. 1 to 2 c.c. may be necessary to produce any distinct coloration of the petrol. Proceed *secundum artem* until the bromine liberated is completely decolorised, time and vigorous agitation being necessary towards the end of the reaction. The amount of chlorine water used indicates the amount of bromine present as bromides.

If the chlorine water used was standardised against solutions of iodide and bromide differing greatly in strength from that of the solution examined, it is desirable to restandardise, using solutions of approximately the strength of the concentrated water.

Estimation of Iodates. To another portion of the concentrated water add 1 per cent. of 33 per cent. acetic acid (free from any trace of mineral acid) and a little pure potassium iodide. Allow it to stand

for at least five minutes, and, if any iodine is liberated, titrate with the sodium thiosulphate, using a single drop of starch solution as an indicator. One-sixth of the iodine estimated will correspond to the iodine present as iodate.

Estimation of Bromates. To the solution in which the iodate has been estimated, add 1 per cent. of pure strong hydrochloric acid, and set aside for half an hour. Estimate the iodine liberated with thio-sulphate, and one-sixth of this multiplied by 80/127 will give the amount of bromine present as bromates.

The following results show the accuracy of the process :—

TABLE I

No.	SOLUTION USED.	SALTS PRESENT—Mgms. per 100 c.c.						
		I in KI	I in KIO ₃	Total I	Br in NaBr	Br in NaBrO ₃	Total Br	
1	Solution in distilled water	{ Taken .	1.0	1.0	2.0	10.0	1.0	11.0
		{ Found .	0.98	1.03	2.01	10.3	1.01	11.31
2	Saturated sol. of NaHCO ₃	{ Taken .	1.0	0.0	1.0	10.0	1.0	11.0
		{ Found .	1.2	0.0	1.2	10.4	1.01	11.41
3	20% sol. of NaCl.	{ Taken .	0.5	0.5	1.0	5.0	0.5	5.5
		{ Found .	0.49	0.55	1.04	4.93	0.51	5.44
4	20% sol. of Na ₂ SO ₄	{ Taken .	0.5	0.5	1.0	5.0	0.5	5.5
		{ Found .	0.52	0.50	1.02	5.2	0.49	5.69
5	Sol. of 10% NaCl and 10% Na ₂ SO ₄	{ Taken .	0.5	0.5	1.0	5.0	0.5	5.5
		{ Found .	0.49	0.49	0.98	5.0	0.47	5.47
6	Sol. of 10% NaCl and 10% Na ₂ CO ₃	{ Taken .	0.5	0.5	1.0	5.0	0.5	5.5
		{ Found .	0.46	0.48	0.94	5.05	0.53	5.58
7	Imitation of a natural brominated water	{ Taken .	2.0	2.0	4.0	70.0	4.0	74.0
		{ Found .	1.8	1.95	3.75	68.0	3.92	71.92
8	containing calcium, magnesium and sodium salts.	{ Taken .	1.0	2.0	3.0	30.0	2.0	32.0
		{ Found .	0.85	2.02	2.87	30.4	2.02	32.42

A trace of nitrite, if present, vitiates all the results.

In the presence of nitrites the bromine cannot be accurately estimated. Upon adding chlorine water to such a solution, many cubic centimetres have to be added before the petrol has any perceptible colour, and the maximum colour produced, even with a strong bromide solution, is only a pale orange. The end reaction is also most indefinite.

2. Estimation of Iodine in Potable Waters

Several methods have been devised for determining the amount of iodine present in potable waters. They are, however, laborious, indelicate and unreliable for estimating the exceedingly minute traces which may be present in waters normally used for drinking and domestic purposes.

The following procedure was devised when standard methods for the estimation of iodine were required in the investigation relating to

the incidence of goitre in this country ¹ (*vide* Chap. XXXVI "Water Supplies and Disease").

Two to five litres of the water are treated with 4 ml. of 10 N iodine-free potassium carbonate solution and evaporated in a nickel dish. When evaporation is almost complete, 2 ml. of 20 per cent. iodine-free sucrose solution are added, the mixture stirred, and evaporated to dryness. The residue is dried at 150°–160° C. and then ignited in a muffle furnace at 480°–500° C. for one hour. The residue is thoroughly extracted with hot water and then rejected.

The aqueous extract is evaporated to dryness in a recently ignited porcelain dish (3½ inches diameter), the residue dried for 30 minutes at 150°–160° C., and finally ignited for five minutes in the muffle furnace at 480°–500° C.

The residue is moistened with water and allowed to stand overnight and then 2.0 ml. of water added gradually, mixing the water into a smooth paste, using a small glass pestle.

The mixture is now extracted by mixing in three separate portions of 5 ml. of iodine-free absolute alcohol, the whole being rubbed with the pestle on each addition of alcohol until finally the potassium carbonate passes into a thin "pasty" condition.

The alcohol is now decanted into a recently ignited platinum dish, 8 cm. in diameter and 100 ml. total volume.

Two further extractions are made with 5 ml. portions of alcohol, and it may be necessary to add small quantities of water to maintain the potassium carbonate in a "pasty" condition.

0.15 ml. of N/1 solution of potassium carbonate is added to the combined extracts, which are then rapidly evaporated on a steam bath in a current of nitrogen which has previously passed through soda-lime. Precaution is taken against contamination by dust.

The residue is dried at 150°–160° C. for five minutes and then ignited at 480°–500° C. *for two minutes only*. The residue should now be free from carbonaceous matter. If traces of organic matter are present, the figure subsequently obtained by titration may be too low.

This necessity for a residue free from organic matter requires that the alcohol evaporation should be rapid (about ten minutes) and that it takes place in a current of nitrogen. This prevents the production of resinous oxidation products.

The residue in the platinum dish is dissolved in 0.5 ml. of 1 per cent. solution of sodium azide and 2 ml. of water, and the solution is carefully poured down a narrow glass rod into a wide-necked, round-bottomed flask of approximately 70–80 ml. capacity. The dish is rinsed twice with 1 ml. portions of water, making a total volume of 4.5 ml. in the flask.

The solution is then made just acid by adding N/2 solution of sulphuric acid and testing the mixture by removing drops with a finely pointed glass rod on to a methyl orange paper. When the solution is just acid, a further 0.05 ml. of the N/2 acid is added, followed immediately by 0.20 ml. of saturated bromine water. A glass bead is quickly added and the bromine boiled off on an asbestos heating board, using a micro burner. The flask rests in a hole in the board of such diameter (approx. 1 inch) that only a portion of the flask holding 1.5 ml. is below the upper surface. The solution is boiled briskly in 2½ to 3 minutes to a volume of 2 ml. As the boiling down proceeds, the size of the flame should be progressively reduced so as to avoid superheating of the glass of the flask above the level of the liquid.

After cooling rapidly in a stream of cold water, 0.1 ml. of a N/2 sulphuric acid solution, 0.1 ml. of starch solution, and 0.1 ml. of potassium iodide

¹ "The Determination of Iodine in Biological Substances," by C. O. Harvey, B.Sc., A.R.C.S., A.I.C. Special Report Series, No. 201, 1935, Medical Research Council.

solution are added. (The starch solution is a freshly prepared 0.5 per cent. aqueous solution of arrowroot starch and the potassium iodide a 2 per cent. solution in distilled water free from dissolved gases.) The liberated iodine is titrated with N/500 sodium thiosulphate solution.

A "blank" experiment is made using 5 ml. of the iodine-free sucrose solution and following precisely the procedure outlined for the actual determination.

As it is difficult to ensure that during the bromine boiling process the solution acquires the same volume in every case, the volume of the solution is measured after titration, and a small correction applied. The correction is $+0.06(V - v)$ gamma where V equals the volume in ml. after titration in the actual determination and v equals the volume in ml. in the "blank" determination. For a satisfactory application of this correction a slight positive "blank" is necessary.

Since the iodine originally present is titrated as iodate, one-sixth of the iodine found by titration represents that present in the water taken. The iodine contents of waters are expressed in terms of gamma (γ) per litre ($\gamma = 0.001$ mg.), i.e., parts per 1,000 million.

Another method is given in "Standard Methods for the Examination of Water and Sewage," American Public Health Association, 1936 Edition. In this method the residues of evaporation from large volumes of water (50 to 100 litres) are completely burnt in a tube and volatile iodine collected in alkali bubblers. The iodine in both ash and alkali is extracted finally with chloroform and the colour matched against standards.

A third method, employing wet combustion of the organic matter, is described in the *J. Assoc. Off. Agric. Chem.*, 1940, 23, 164-171. Here again the iodine eventually extracted is matched by colour depth against standards.

3. Detection and Estimation of Fluorine

Since 1931, when Churchill⁽¹⁾ indicated the probable significance of fluorides in drinking water, so many different methods of estimation have been advanced as to suggest that none is free from difficulty and criticism. There is general agreement, however, that colorimetry is best adapted to routine water analysis, and the original procedure devised in 1924 by de Boer⁽²⁾ has been incorporated in the majority of recent determinative methods. De Boer showed that minute amounts of fluoride cause a zirconium-alizarin mixture in hydrochloric acid solution to change colour from pink to yellow, the degree of fading being proportional to the quantity of fluorine present.

It was subsequently discovered that the ordinary saline constituents of water (e.g., sulphates, chlorides, bicarbonates, calcium and many other ions) could, if present in sufficient concentrations, inhibit the fading action of the fluoride to a greater or lesser extent, thereby inducing erroneously low results. By increasing the acidity, Barr and Thorogood⁽³⁾ Elvove⁽⁴⁾ and Sanchis⁽⁵⁾ have removed many of these difficulties, as, by their methods, the concentration at which each interfering substance exerts any appreciable effect is above that in which the substance normally occurs in the majority of natural potable waters.

For determining the fluoride content of discoloured or unusual waters the steam distillation process of Hoskins and Ferris ⁽⁶⁾ (described later) should precede the colorimetric test. By this means the fluorine is separated from interfering substances, colorimetry being applied to the distillate. This procedure is preferable to the employment, as standards, of synthetic waters having the same mineral composition as the water under examination.

We have found Barr and Thorogood's modification of de Boer's process to be the simplest and most suitable method of direct colorimetry. The summary of the method is quoted herewith :—

"To 50 ml. of the water, contained in a Nessler glass, add 2.5 ml. concentrated (10 N) HCl; mix, and then add such a quantity of the following reagent that a very faint pink tinge remains after standing for 10 minutes. The reagent is made by mixing 3 ml. of a zirconium solution (3.53 gms. $ZrOCl_2 \cdot 8H_2O$ per 100 ml. of water) with 1 ml. of a 1 per cent. solution of sodium alizarin monosulphonate in water, and diluting to 200 ml.; for fluorine contents below 1 part per million, 2 ml. of the reagent give a sufficiently intense pink colour, whilst for 5 parts of fluorine per million 4 ml. will be required, and will yield an orange colour. The colour produced must be matched against that given by standards containing known concentrations of fluorine (as sodium fluoride) treated similarly and at the same time.

"When the order of concentration is unknown, it is convenient to make a preliminary estimate from the *rate* of disappearance of the pink colour, using 4 ml. of reagent with standards containing 1, 2, 4 and 8 parts of fluorine per million."

The following method is recommended for preparing the standard solutions :—

A. Strong Fluoride Solution (1 ml. corresponds to 1 mgm. F.). Dissolve 2.21 grammes of sodium fluoride in distilled water and make up to 1 litre.

B. Dilute Fluoride Solution (10 ml. correspond to 0.1 mgm. F.). Dilute 10 ml. of "A" to 1 litre.

Preparation of Standards :—

Volume in ml. of "B" to be diluted to 50 ml.	5	10	20	40
Strength of standard in parts F per million	1	2	4	8

When the preliminary estimation has indicated the approximate fluorine concentration, further standards are made ranging around the expected level but differing from one another by only 0.2 part per million, and the test proper is then applied. It is stated that matching can be accurately secured after the solutions have stood for only ten minutes, but we have found that the slight differences in colour are more easily distinguished after the solutions have stood overnight. In the absence of complications it is possible to attain an accuracy of ± 0.1 part per million.

Using this method on natural and synthetic waters we find that

calcium, magnesium, sodium, bicarbonates, sulphates and chlorides up to 25 parts per 100,000, silica up to 3 parts per 100,000, and phosphates, copper and iron up to 0.5 part per 100,000 do not interfere with the quantitative determination of fluorides, but that minute traces of aluminium above 0.05 part per 100,000 have a serious effect, results being low, whilst free chlorine above 0.5 part per million, and manganese and zinc at 1 part per 100,000 cause a positive error.

Therefore, before reliance can be placed on the results of the direct test it is necessary to have excluded the possibility of interference by means of a complete "mineral" analysis of the water to be examined. Some investigators recommend that the distillation technique should be adopted as a routine, but, as the majority of natural drinking waters in this country, provided they are clear and bright, are amenable to direct determination, we prefer to reserve the distillation for those cases in which it is essential, *e.g.* :—

(a) Where the water is discoloured or turbid.

(b) Where the preliminary analysis indicates interference in the direct method.

(c) Where confirmation of the direct test is desired.

The modification by Hoskins and Ferris⁽⁶⁾ of the distillation method of Willard and Winter,⁽⁷⁾ as described by Sanchis,⁽⁵⁾ is to be recommended in such cases, and, as the details are of considerable importance, Sanchis' description is quoted in full :—

"STEAM DISTILLATION FOR THE ISOLATION OF FLUORINE FROM INTERFERING SUBSTANCES AS HYDROFLUOSILICIC ACID.

Reagents :—

Concentrated sulphuric acid, C.P.

Silicic acid powder, C.P.

Glass beads, 3 mm. diameter.

Red litmus paper.

Sodium hydroxide solution, 4 per cent.

Apparatus. The apparatus consists of a 250 ml. capacity Claissen flask which is connected to a Liebig condenser of 300 mm. jacket length. The neck of the distilling flask carries a perforated rubber stopper which supports a 200° C. thermometer and a 6 mm. O.D. glass tube. This tube reaches down to the bottom of the flask and is used to lead the steam, generated in an auxiliary boiling flask of 1 litre capacity, into the sample being distilled.

The perforated stopper on the auxiliary boiling flask carries, besides a steam outlet, a 7 mm. O.D. glass tube 3 feet long which extends beneath the surface of the water in the flask and has for its purpose the release of surges of pressure.

Two ring stands, two burette clamps, two clamp rings, two wire gauze squares, a condenser clamp, several feet of rubber tubing, two gas burners, and two screw clamps complete the needed equipment.

Procedure. Place a small piece of litmus paper in a 150 ml. aliquot of the sample and add 4 per cent. sodium hydroxide solution, dropwise, with constant stirring until the litmus paper turns blue. Remove the litmus paper with the stirring rod and boil down the sample to a volume of 50 ml. If the aliquot has appreciable quantities of calcium and magnesium, a decided floc will be formed during this operation.

After cooling the sample, just enough concentrated sulphuric acid is added, dropwise, to redissolve the floc and the material deposited during

evaporation on the sides of the beaker. The temperature of the solution must not rise appreciably throughout this operation.

Place 5 glass beads and 0.2 gram of silicic acid powder in the Claisen distilling flask. The prepared sample is then carefully transferred from the beaker so as to rinse down any silica powder which may have adhered to the neck of the flask, finishing the transfer by rinsing with distilled water from a wash bottle.

While keeping the contents of the distilling flask cool, by allowing cold water to flow slowly on the surface of the flask, and in constant motion, add carefully 10 ml. of concentrated sulphuric acid.

Connect the distilling flask to the steam generator and condenser and start the distillation by raising the temperature of the contents of the distilling flask slowly, until it reaches 100° C. After 5 or 10 ml. have distilled over, the burner flame is increased sufficiently to allow the distillation to proceed at about 30 drops per minute. In the meantime, the water of the auxiliary flask is brought to the boiling point and maintained there without allowing an appreciable amount of steam to come into the distilling flask until the temperature reaches 135° C. At this point the burner flame under the boiling flask is increased and that under the distilling flask is decreased as much as necessary to maintain the temperature of the contents of the distilling flask at 137° to 140° C., while distilling at the rate of about 70 drops per minute, until 150 ml. of distillate have been collected. The gas flames may be controlled conveniently by means of screw clamps.

The syphoning of the contents of the distilling flask into the boiling flask while cooling, after distillation is over, may be prevented by placing a pinch clamp on the rubber tubing which connects the two flasks.

For success in the distillation, a steady rate of distillation at the specified temperature must be maintained and the contamination of the delivery tube by spray, which results from bumping, or by the careless addition of the sample and reagents, must be avoided."

The distillate can now be submitted to the colorimetric test as already described. If 150 ml. of sample are used in the distillation and 150 ml. of distillate collected the colour standards will give directly the amount of fluoride in the original sample of water. This method has, however, the added advantage that it gives a ready means of concentrating the fluoride content where desired. The distillation procedure, on the other hand, requires "more than ordinary care, and, in the hands of an inexperienced worker, the results may be disappointing."

References

- (1) CHURCHILL, H. V. *Indust. and Eng. Chem.*, 23, 996 (1931); *J. Amer. Water Works Assoc.*, 23, 1399 (1931). "The Occurrence of Fluorides in Some Waters of the United States."
- (2) DE BOER, J. H. *Chem. Weekblad.*, 21, 404 (1924).
DE BOER, J. H., and BASART, J. A. *Zeit. Anorg. Allgem. Chem.*, 152, 213 (1926). "A Rapid Volumetric Determination of Fluorine."
- (3) BARR, Guy, and THOROGOOD, A. L. *Analyst*, 59, 699, 378, June, 1934. "The Determination of Small Quantities of Fluorides in Water."
- (4) ELVOVE, E. *U.S. Pub. Health Rep.*, 48, 1219 (1933). "Estimation of Fluorides in Water."
- (5) SANCHIS, J. M. *J. Amer. Water Works Assoc.*, 28, 1456 (1936). "Methods of Testing and Significance of Fluorine and Fluorides in Water Supplies."
- (6) HOSKINS, W. M., and FERRIS, C. A. *Ind. and Eng. Chem.*, Anal. Ed. 8, 6 (1936). "A Method of Analysis for Fluoride."
- (7) WILLARD, H. H., and WINTER, O. B. *Ind. and Eng. Chem.*, Anal. Ed. 5, 7 (1933). "Volumetric Method for Determination of Fluorine."

4. The Measurement of Radioactivity

Occasionally the analyst is asked whether a sample of water contains radium. Without making an analysis he may quite confidently state that it contains that substance or its emanation, but if he is asked to determine the amount he must be prepared to use special apparatus. He must also have had some special experience before he can translate his results into actual figures with any degree of confidence. The few remarks made here on the measurement of radium are based upon Joly's work, "Radioactivity and Geology,"¹ which should be consulted.

There is very little evidence to show that the radioactivity of a natural water gives it any special therapeutic property, but large claims have been made as to its beneficial effects. Reference to Joly's work will show that radium and its products of disintegration are found everywhere in sea water, spring and river waters, in the air, and possibly in every mineral. In fact, it is ubiquitous. The proportions present in the ocean seem to vary in different localities from 0.004×10^{-12} grammes per cubic centimetre in the Indian Ocean off Madras to 0.084×10^{-12} in the Atlantic round the Irish coast, the mean being 0.017×10^{-12} grammes per cubic centimetre. Joly estimates that the oceans contain about 20,000 tons of radium. If rivers were the only sources of replenishment they would have to discharge into the seas $1/2540$ th part of that amount annually in order to make good the loss and degradation. There is no evidence of any such amount being so carried and the radium must therefore be replaced from rocks and other sources. The Nile water contains only 0.0042, and the Rio de la Plata water 0.0052×10^{-12} grammes per cubic centimetre.

Joly stated: "The widespread presence of radium in the rocks affords an explanation of emanations, not only in spring waters, but in air drawn from soils and in the air of caves."

There appears to be little doubt that the occurrence of helium in springs, in natural gases, and in the atmosphere (in which, according to Ramsay, it exists to the extent of 4 parts in 10,000) must be ascribed to the general diffusion of unstable elements in the surface crust of the earth, since there is no longer any question of the identity of helium with the alpha rays given off by radium.

Thomson first discovered radium in water. He showed its presence in Cambridge tap water, and apparently it could be found in every sample of water if carefully examined.

Joly's apparatus consists of (a) a flask for boiling the water with an inverted condenser attached, (b) a bulb tube for collecting the gases evolved, (c) a drying tube containing phosphoric anhydride, (d) an electroscope. In addition, an air pump is required, and also a microscope with a scale division, dividing the field into 100 parts in the eyepiece. The illustrations in Fig. 23 show the apparatus, made for us by Messrs. Gallenkamp & Company, London. The water is boiled in the flask *a* with condenser attached for thirty minutes. It is then

¹ Messrs. Archibald Constable & Co. Ltd., London, 1909.

allowed to cool and the flask closed and put aside for from twenty-four hours to three weeks. It is then again attached to the condenser. The bulb tube *b* is then exhausted of air by means of the air pump and connected to the condenser. Upon removing the lower pinchcock the pressure in the apparatus is reduced. The water is now boiled for thirty minutes, the condenser being kept cold, and the gases dissolved in the water and the radium emanations are boiled out. Cold distilled water is then run into the flask through the short bent tube in *a*, and the whole of the gaseous contents of the flask and condenser are forced

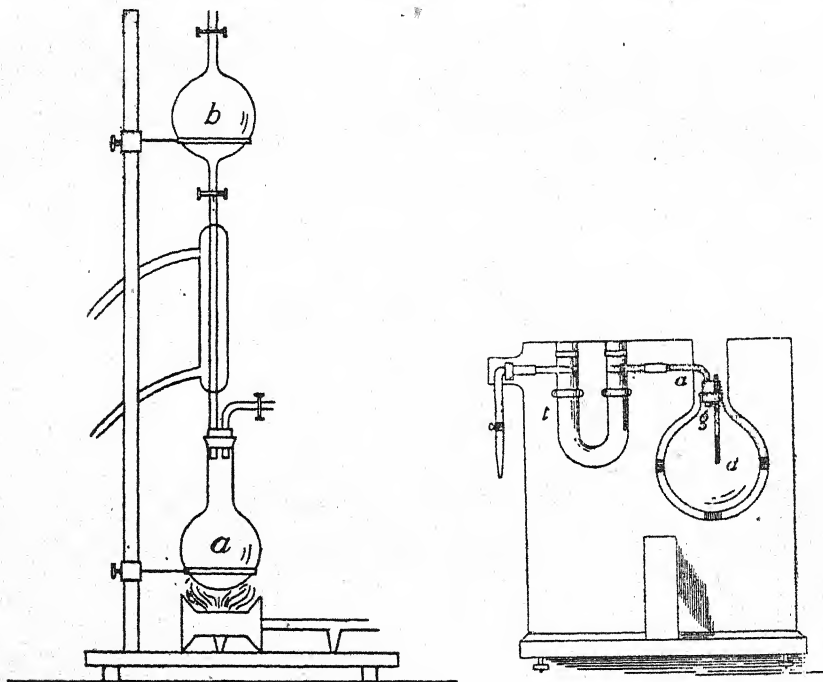


FIG. 23.

into the bulb tube *b*. Meanwhile, the drying tube and electroscope have been exhausted of air and the tube connected with the drying tube, the electroscope charged, and the normal leak of the electroscope ascertained. The bulb tube *b* is then connected to the drying tube and the pinchcock at the connected end removed.

By carefully opening the tap on the drying tube some of the gas is drawn into the electroscope. The remainder is forced in by pouring more water through *a* by means of a funnel and long tube, until the bulb tube *b* is full of water. By this means all the gases evolved from the water are transferred to the electroscope. When the gases have all been discharged, a reading should be taken of the rate of collapse of the gold-leaf, and in three hours a second reading should be taken. If radium is present in the water, the rate of collapse will

be found to have increased some 30 to 40 per cent. over the first reading. If actual measurements are to be attempted several precautions must be observed. The deflection of the gold-leaf at the commencement of the experiment should not exceed 30 degrees. There should be no possibility of contamination by radio-active substances in the laboratory, and the water should remain clear during ebullition. This necessitates the addition of a little pure hydrochloric acid to the water in many cases. Notwithstanding this admonition, Joly recommends the placing of a little powdered steatite in the condenser, so that the condensed steam may carry it into the boiling flask and thus ensure the effervescent type of boiling.

Joly gives a table by aid of which, after the electroscope has been calibrated, the amount of radium present in the water can be estimated; but for this and other details his work should be consulted.

Ramsey, in his "Report on the Mineral Waters of Bath," gives the following table:—

Radium in the water of the King's well.	0.1387 mg. per million litres.
Niton (radium emanation) in King's well.	1.73 ¹ " " "
Niton (radium emanation) in Cross Bath	1.19 ¹ " " "
Niton (radium emanation) in Hettling Bath	1.70 ¹ " " "
Niton (radium emanation) gas from King's well	33.65 " " "

He quotes MacOwen's results, as under, for the Buxton waters:—

Hospital natural bath	0.83 mg. per million litres.
Crescent pump room	0.83 " " "
Gentleman's natural bath	1.10 " " "
Natural gas from Buxton waters	7.7 and 8.5 " " "

¹ These figures are the weights of radium capable of forming the niton present in the waters and gas.

PART VI

CHAPTER XXIV

THE WATERS OBTAINED FROM VARIOUS GEOLOGICAL FORMATIONS

THE ordinary sanitary analyses give very little information of value with reference to the saline constituents of waters from different sources. The more complete analyses, which include the estimation of the more important acids and bases, are often of value for sanitary purposes, and are imperative in determining whether waters are suitable for boiler and special manufacturing purposes. Records of such analyses must ultimately assist in the elucidation of many problems of considerable geological importance, especially those connected with the flow and distribution of underground waters.

A discussion of these questions is beyond the scope of this volume, but numerous analyses of waters from the most important water-bearing strata are given in Chap. XXV, as they will probably be useful, and may lead others to record analyses from these and other strata. With very few exceptions, all the analyses were made in our laboratories. The exceptions are indicated by an asterisk in the tables.

The Memoirs of the Geological Survey published up to date deal with water supplies in the following Counties :—

Bedfordshire and Northamptonshire.	Lincolnshire.
Berkshire.	London County.
Buckinghamshire and Hertfordshire.	London Wells.
Cambridgeshire, Huntingdonshire and Rutland.	Norfolk.
Derbyshire.	Nottinghamshire.
Dorset.	Oxfordshire.
Essex.	Somerset.
Gloucestershire.	Suffolk.
Hampshire (including the Isle of Wight).	Surrey.
Herefordshire.	Sussex (with 2 supplements).
Kent.	Warwickshire.
Leicestershire.	Wiltshire.
	Worcestershire.
	Yorkshire, East Riding, etc.

All these contain such analyses as were available, and should be consulted with reference to the characters of the waters derived from underground sources in each county. It is unfortunate that the number of complete analyses of waters from many of the counties is very small, but, such as these are, they are informative and useful. The advantage of consulting the Memoirs is that details are recorded, such as sections of wells, etc., which could not be given here without rendering the tables of Chap. XXV unwieldy.

A study of the analytical results will show how difficult it often is to decide from what source a water has been obtained. It is not uncommon at certain examinations to submit the results of a partial analysis to a student and expect him to say from what geological source the water has been derived. Some of these analyses have been submitted to us, and we have been quite unable to determine the source. The fact is that it is not generally known to what an extraordinary extent waters from the same geological formation vary in character. One of the most important causes is the character of the superimposed strata, and another is the distance which the water has had to travel from the outcrop of the water-bearing stratum to the point at which the water is abstracted. These alone do not, however, account for all the variations. A water may issue from a fissure in one kind of rock, but may really be derived from rocks of an entirely different formation. In Essex, many wells are bored into the Chalk, yet the whole of the water derived therefrom comes from the Thanet Sand lying upon the Chalk. A well sunk in superficial sands and gravel may yield a hard or soft water, the character depending upon the presence or absence of boulder clay in the vicinity. In some of the drift-covered valleys the superficial springs on one side yield a fairly soft water, whereas on the other the water may be so impregnated with salts of calcium and magnesium as to be quite unfit for domestic purposes. In the latter case boulder clay will usually be found on the higher ground capping the gravel.

The great majority of the analyses given are of waters either used for public supplies, or examined to ascertain if they were suitable for this purpose. The hygienic character of most of the waters is indicated by the results of the estimation of the free and albuminoid ammonia, and oxygen absorbed.

The silica has sometimes been estimated, but, where not recorded separately, the "silica, etc.," is merely the difference between the total of the saline constituents estimated and the total solids obtained by drying at 180° C. In some waters, peaty matters account for the "etc.," in others, suspended clayey matter, which could not be removed by simple filtration, increases the amount, and, of course, any slight errors in the analyses also affect this item.

Surface Waters from Various Districts (Nos. 1-22). Nos. 1 to 10 are chiefly on the Coal Measures. It is rarely necessary to make detailed analyses of such waters. Magnesium sulphate and sodium chloride and nitrate occur in the majority. Calcium carbonate is absent from four, and these would act vigorously on lead, especially if they contained much CO₂ in solution. Nos. 9 and 10 had practically no action on that metal, whilst 1, 6, 7 and 8 had some action. The only one which contained an appreciable amount of iron was derived from near Bury, where there was an outcrop of ferruginous shale. Nos. 11 to 22 are typical reservoir or lake waters. Other details of such waters will be found in Chapter XLV.

River Waters (Nos. 23-66). Nos. 23 and 24 are streams on Dartmoor, and most of the others are waters utilised, or proposed to be

utilised, for the purposes of public supplies. River waters vary considerably in character according to the geological formation of the areas from which they are derived and through which they flow, and they vary also with the season, as already noted in Chapter V.

The Thames water at Grays, No. 40, was examined because of suspected infiltration into the Chalk in that locality. When pumping is excessive in the chalk quarries, magnesium chloride and sulphate make their appearance in the water, together with a much larger quantity of common salt. Bromides, not referred to in the analyses, can also be detected in the chalk-water when the chlorides markedly increase.

No. 58 is a sample from an intermittent river or a bourne.

Spring Waters (Nos. 67-90). Many of these yield part of the water of public supplies, while others merely provide the supplies to a few houses. Nos. 70 and 77 are spring waters used for bottling and table use.

The largest spring supply in this country is that of Portsmouth, and an analysis of this water is given in No. 439.

Shallow Well Waters (Nos. 91-135). Nos. 91-123 are chiefly from the Drift. With the exception of Nos. 101 and 102, which are of alluvial origin, all the others were used for drinking and domestic purposes. Nos. 101 and 102 are impregnated with sea-water, and, apparently, any nitrates the waters may have originally contained had been reduced to ammonia. Each well was sunk to ascertain if the water was usable for domestic and boiler purposes, but it certainly was not. Nos. 109 to 123 are all from wells in actual use when the samples were collected. Note the amount of nitrate in 115.

Nos. 124-129 are waters from the Crag in Suffolk. With one exception they are exceedingly hard, and two are ferruginous. One acted vigorously on galvanised iron pipes, taking up a considerable amount of zinc. No. 124 is possibly affected by its proximity to the sea.

Nos. 130-135 were derived from the Bagshot Beds, and these, apparently, may yield a hard or a soft water. In Essex, such waters contain little or no calcium carbonate, and have given rise to cases of lead-poisoning where lead-piping has been used for the construction of the pumps or for raising water from the wells. The well from which the Gosport sample was derived is over 200 feet deep, and the London Clay is said to have been reached at about 206 feet. The well at Parkstone is 277 feet deep, and yields a pure and constant supply of water. The only constituent common to all is sodium chloride.

Waters from the Lower London Tertiaries in Essex and Kent (Nos. 136-168). Almost certainly all are from the Thanet Sands, as the upper beds contain so much clay that it is doubtful whether any water can be obtained from them. The possible exceptions are Nos. 139, 144, 157, 159 and 162, but all the information with reference to these wells is that they are sunk through the London Clay and yield very little water. It is possible, therefore, that the bores terminate in the Blackheath, Woolwich, or Reading Beds.

These exceptional waters contain no sodium carbonate and varying

amounts of magnesium sulphate, whereas all the waters undoubtedly derived from the Thanet Sand contain sodium carbonate and no magnesium sulphate. The type is characteristic, and the source of the constituents is discussed in Chapter III.

A remarkable change is shown in the water from the Tollesbury well (136-137). At a depth of 187 feet, the clay had been pierced and water rose in the bore-tube. The analyses of this water are given in No. 136. The boring was continued to 256 feet, and the water again examined, when it was found that the chlorides had increased and the sulphates had markedly decreased.

The Bulphan Fen water (No. 162) can scarcely be affected by the sea, since the water-level in the well is 18 feet above O.D. This bore does not overflow, but others nearby still overflow from pipes about 3 feet above the ground-level, 18 feet + O.D. The water from the overflowing wells is normal in character, that is, it contains sodium carbonate and sulphate, but the amount of common salt is unusually low, 8.1 parts per 100,000.

Nos. 166, 167 and 168 provide an interesting example of the great variation which may occur in the characters of waters derived from separate boreholes sunk into the same formation and within a mile or so of one another. It was expected when borehole No. 167 was constructed that a soft water similar to No. 168 would be obtained.

Waters from the Chalk under the Lower London Tertiaries (Nos. 169-280). The remarkable similarity between the Thanet Sand waters and the waters Nos. 169-216, derived from the Chalk in the same localities, leaves no room for doubt that the chalk water in parts of Essex is really derived from the Thanet Sand and the other Lower London Tertiaries. (See also London deep wells, Nos. 217-280.) When the results of a series of analyses of this kind are plotted out on the geological map, their importance becomes manifest. The direction of the flow of the underground water can often be traced and the causes of the variations ascertained. The nature of the water which will be obtained by boring at any particular spot can sometimes be foretold with a fair amount of accuracy, and, when details of the yield of other borings, the level of the water, etc., are recorded, the amount of water obtainable can also be predicted. Most of the hard waters in this series are found to be derived from wells near the outcrop of the Chalk, where the water has not been fully softened by the action of the Thanet Sands, referred to in a previous section. Curious anomalies are brought to light and open out fields for further investigation. For example, at Wivenhoe the well No. 199 yields a water containing less salt than the well No. 200, yet the latter well is farther from the tidal estuary. The wells Nos. 171 and 172 are only about a mile apart, yet one is comparatively soft and the other very hard, and a line of demarcation can be drawn, upon one side of which the Chalk yields a soft water, whereas upon the other side the yield is a hard water. Several examinations were made during a boring at Layer Marney which was carried down to 1,000 feet. They showed a gradual increase in the amount of salt present. The yield of

the bore was very limited, not enough to supply a mansion and outpremises, and it was therefore abandoned. In other parts of Essex, where similar trials have been made, the same results have been obtained.

Nos. 217-280 suggest that the water derived from the Chalk under London and neighbourhood is the same as that obtained in central and southern Essex. Near the Thames, however, there are many wells yielding water containing an admixture of tidal water, showing that the Thames water gains access to the Chalk. About this there can be no doubt, and the result may be that the multiplication of deep wells in the Metropolis, and the increased draught of water from the Chalk, will result in a serious impregnation of the whole of the water-bearing stratum with sea water. Evidence now available shows that this result can already be detected. No. 217 is an example of the water which is occasionally met in the London Clay during tube-driving to the Chalk. It usually has an odour of sulphuretted hydrogen, contains much sulphates and is excessively hard. On the south of the Thames the Chalk yields water of most diverse character. At Bermondsey, a well (No. 254) yielded a water with a hardness of 60 parts per 100,000.

Other wells in the locality yield waters which are soft in comparison, but the depth of the Chalk varies so much that an investigation of the area would be interesting. Our notes chiefly refer to the north of the river, but apparently many wells have been sunk also on the south side, and some of the records may be available. Unfortunately some well sinkers do not keep details, and those of others are often unsatisfactory. Well sinkers of repute keep accurate records and deposit them with the Geological Survey Office, Exhibition Road, South Kensington, S.W., where they can be consulted. Records of every well which pierces the superficial stratum ought to be deposited with this Office, and the point indicated on the map where the well is sunk or the boring made.

A Memoir on the Water Supply of the County of London from Underground Sources has been issued (1937).

The characteristic waters of the Thanet Sand and underlying Chalk, *i.e.*, those which are soft, alkaline, and rich in sodium salts, often exhibit marked corrosive action on iron and steel. Attempts to correct this activity have been made by adding to the water minute doses of lime or a mixture of lime and gypsum. The waters are not plumbo-solvent, and copper withstands their action.

Chalk Waters, Essex (Nos. 281-295). These are analyses of waters from wells on or very near the Chalk outcrop in Essex. They are of a totally different character from those just considered. Not one contains any sodium carbonate, and calcium or magnesium nitrates are common. In fact, calcium and magnesium salts predominate, whereas, farther from the outcrop, sodium salts more or less completely replace them. At the Purfleet chalk outcrop, tidal water enters the Chalk freely, and, by pumping in the chalk quarries, this influx is rapidly increased and the salt content proportionately raised. Waters 289

and 290 are from the same well, 290 under fairly normal conditions, and 289 after pumping has been continuous and the water-level lowered. The effect of the influx of water from the river is most marked.

Chalk Waters, Herts (Nos. 296-317). These may be said to be of a uniform type, but there are considerable variations in the quantity of saline matter present. Thus, at Berkhamstead the water only contains 26.5 parts per 100,000, whereas elsewhere it may exceed 50 parts. Wells Nos. 304-306 are close together, yet the proportions of the saline constituents vary widely.

Chalk Waters, Suffolk (Nos. 318-331). In this county the character of the water varies enormously in different districts, and the total saline constituents vary in the examples given from 41 to 530 parts per 100,000. The water from a bore made at Shotley (No. 325), about one-eighth of a mile north of the tidal river Stour, is evidently impregnated with tidal water. The Chalk is here covered by about 100 feet of clay and sand, and no water was obtained until a depth of 148 feet was reached, 111 feet below tide-level. In the Stour Valley water is entering the Chalk, probably in several places, and its effect is evident on both sides of the river. Occasionally the water is very ferruginous.

Chalk Waters, Norfolk, Cambridge, Beds., and Lincs. (Nos. 332-353). Except in Lincolnshire, the variations in these waters do not appear to be so great as in Suffolk. These waters may be ferruginous, the Lincolnshire one (No. 351) being also very hard and having a high salt content.

Well No. 350 is said to be a Greensand water, but it certainly has the characteristics of a Thanet Sand water. The well is near Skegness, six miles from the sea, and the water overflows.

Chalk Waters, Middlesex (Nos. 354-359). Some of the boreholes in the metropolitan area of the county yield the typical soft, alkaline, sodium waters of the London Basin. (See Nos. 217-280.) As the Chalk nears its outcrop, and the Thanet Sand disappears, the water becomes harder and contains less sodium. No. 355 is a relatively soft water, rich in sodium salts, but free from the carbonates of soda. In other areas, the water is harder and approaches the character of chalk water unaffected by zeolitic influences.

Chalk Waters, Surrey (Nos. 360-370), Sussex (Nos. 371-381), Bucks (Nos. 382-392). These waters generally resemble one another, and conform to the type of water known as a typical chalk water.

The level of the chalk water may at times come above the surface in the valleys, and thus form a bourne. An analysis of this water is shown in No. 58.

No. 372 differs from the general type, and is probably not derived from the Chalk.

Chalk Waters, Berks. (Nos. 393-411). These waters show considerable variation, but can be divided into two groups, as in the case of the Essex chalk waters. Thus, Nos. 403-411 are all derived from the Chalk underlying the London Tertiary Beds, and with the exception of

No. 411 all contain sodium carbonate. They appear to be intermediate in character between the true tertiary waters and the typical chalk waters shown in Nos. 393-401. A further boring was made on the site of No. 403 to a depth of over 1,000 feet, and the Chalk was pierced but no water was obtained from the Greensand. It is possible that No. 403 was affected by admixture of water from overlying strata, probably the gravel.

Chalk Waters, Oxon (Nos. 412-413), Rutland (No. 414), and Dorset (Nos. 415-418). Here again the variations observed are not very great. Some, in Dorset, show that they are to a very slight degree affected by their proximity to the sea, in comparison with others which are entirely unaffected. In certain of these localities, excessive pumping causes an increase of chlorides in the water, showing that the influx of sea water is being accelerated.

Chalk Waters, Hants (Nos. 419-447) and Isle of Wight (Nos. 448-453). Many of the wells from which these waters are derived are near the sea and show the effect of such proximity. The Foxbury well was originally a source of public supply, but the salinity increased so rapidly that the well and adits had to be abandoned. When examining the adits, samples were taken from the various fissures through which water was entering, and the one causing the trouble was found (No. 422). When it was closed the same water issued from other fissures, and all attempts to cut it out ended in failure, hence the abandonment of the works. Well No. 427 is over 700 feet deep. When an excessive amount of chlorides is found in any stratum, it is useless sinking deeper in the hope of obtaining a better water from the same stratum, as almost invariably the salinity increases with the depth. Large sums of money are wasted in useless borings, owing to lack of competent advice. Of course, if another water-bearing stratum can be reached, there may be hope of obtaining a better water, but the probabilities are not great. The Woolston boring (No. 435) near Southampton illustrates this. At a depth of 450 feet and above the Chalk, water was obtained containing 45 parts per 100,000 of hardness and 63 parts of chlorine. The boring was continued into the Chalk to a total depth of 870 feet, when the hardness was found to have increased to 50 and the chlorine to 84 parts per 100,000. The water was also discoloured and ferruginous. Several boreholes in the Romsey area yield ferruginous waters (No. 440).

Chalk Waters, Kent (Nos. 454-479). Calcium and magnesium nitrates are present in many of these waters, doubtless derived from manurial matter by oxidation. As might be expected, some of the wells near the coast or Thames estuary show the infiltration of tidal water, and the salt content of a number of well waters still in use is gradually rising year by year. Some, after many years of use, have now had to be abandoned on this account. At Herne Bay (No. 472) the Chalk is covered by 210 feet of tertiaries, and though the boring goes 70 feet into the Chalk, there is no doubt that the whole of the water is derived from the Thanet Sands. The potassium salts present in this

sample were estimated, as the flame reaction indicated that more were present than in Essex Thanet Sand waters. The gases in solution and the free and semi-combined carbonic acid were also determined, and it was found that the CO_2 present was just sufficient to convert all the carbonates into bicarbonates, no CO_2 existing in a free condition. This is the case with all the Thanet Sand waters yet examined.

Chalk Waters, Yorks. and Wilts. (Nos. 480-486). Note the comparatively large amount of common salt in the waters from the Chalk in S.E. Yorkshire, and that two of the three samples were ferruginous. Wells Nos. 480 and 481 are fairly close together, but No. 480, which is a deeper well and on higher ground, contains much more salt than 481. Few successful borings appear to have been made into the Chalk in this locality; either the amount of water obtained has been very limited or the quality unsatisfactory.

The water derived from the Chalk in Wiltshire, Nos. 483-486, appears fairly typical and without unusual features.

Greensand Waters (Nos. 487-538). It does not appear possible to distinguish between water derived from the Upper and the Lower Greensand, and waters from both sources vary greatly in character. They frequently resemble chalk waters, but are more likely to be ferruginous.

The superficial waters, such as the spring at Shere, No. 489, and the shallow well at Godshill, No. 537, contain very small amounts of chlorides, and are not very hard. The Westwood water, No. 504, is stated to be derived from the Gault but is doubtless from the Hythe Beds. The Surrey waters are mainly from wells of moderate depth in the Hythe Beds, but some (Nos. 494, 496, 501) are of considerable depth. Their yields are, however, comparatively small. In certain areas, sands of different colours are present, separated by beds of clay, and yielding waters of different characters. In the Wing boring (527), different samples examined varied in hardness from 20 to 55 parts per 100,000. The water from the Linslade boring (517) varies in character, the hardness on one occasion being only 25 parts per 100,000.

Weald Clay Waters, Surrey (Nos. 539-544). The Weald Clay appears to be very rich in zeolites, invariably yielding waters of high sodium carbonate content and usually very soft. Nos. 540 and 541 were obtained from the same borehole, the saline water of the former, met at less depth, overflowing at the surface. The yields of these wells are small.

Hastings Sands Waters (Nos. 545-560). These sands almost invariably yield waters containing iron and manganese, and the variations in character are very considerable. The boring at Styce Place (549) is 830 feet deep, and water in percolating to this depth has evidently passed through some zeolitic stratum, which has substituted sodium for the calcium and magnesium in the salts originally present in the water. The water overflows from the borehole, and has been in use for many years for drinking, brewery and industrial purposes, without complaint. Note its high content of carbonates of soda, and the close similarity to

No. 541, a water obtained from a boring in the Wealden in Surrey.

Waters from the Oolites (Nos. 561-605). The Purbeck Beds yield little water; No. 561 came from a well near Swanage. Water entering this well at different levels varied in hardness, but was always very hard and contained considerable quantities of calcium carbonate and sulphate. About a third of the examples given contain sodium carbonate, some in large amounts. Others contain excessive amounts of sodium chloride, and in the Woodhall Spa water (No. 572) this is associated with much magnesium chloride which would have suggested some connection with tidal water had the well been near the sea. It also contained bromides, bromates and iodides and is a medicinal, and not a potable, water. Note also the highly saline character of No. 574 derived from a boring near Huntingdon. Most of the waters contain sodium sulphate, No. 563 being a typical water from the Oxford Clay. No. 588, resembling a normal chalk water, was derived from the Cornbrash, while No. 576 came from the Kimmeridge Clay. In general, the variations are very great and there are no definite characteristics. The hardness figures vary from 5 to 65 parts per 100,000, and the waters are occasionally ferruginous.

Waters from the Lias (Nos. 606-626). These represent waters from various parts of England. Most contain magnesium sulphate and are very hard. In some, the permanent hardness exceeds the temporary. No. 623 is from a 95-foot boring into the Lower Lias, and Mr. Preston, F.G.S., states that it comes from the ironstone band in the zone of *Ammonites varicostatus*. Sodium carbonate is sometimes present, and the water may contain much sodium sulphate and chloride, see Nos. 615 and 623.

Boreholes Nos. 607 and 608 are said to derive the water from the Midford Sands.

Waters from the New Red Sandstone (Nos. 627-692). These are derived from many counties. The variations observed are enormous. Many are excessively hard, a few comparatively soft. All contain magnesium salts, some in small quantity, many in large quantity. No. 687 was derived from a boring 1,800 feet deep, and no record appears to have been kept of the strata passed through. Our informant said that the boring passed through three beds of coal and three of fire clay; that at 870 feet water was found; and at 1,800 feet boring ceased because no more water was obtained. He added: "There is from one-half to one mile of the New Red Sandstone which contains barium." As the Coal Measures are below the N.R.S., it is difficult to see how New Red Sandstone could have been met with in this boring. This sandstone does outcrop near Ilkeston, but possibly the Old Red Sandstone is intended. No. 688 is from a boring 400 feet deep into the Keuper Sandstone. In South Lancashire, the water yielded varies in character; in sinking one of the wells near Warrington, water entered at three different points, and these waters varied much in hardness. The opinion expressed was that by cutting out the two upper sources a water of good character would be obtained, and this proved to be the

case, a water of 17 to 18 parts per 100,000 of hardness being the result. In the Mouldsworth borings (Nos. 680 and 681) the top water was harder and contained more sodium chloride. All the New Red Sandstone waters contain appreciable quantities of magnesium salts, some as carbonates, others as sulphates, and many as chlorides. The amount of sodium chloride is usually small, but in some cases it is excessive. The Avonmouth water (No. 690) is from a boring made to obtain a potable water. It was 73 feet deep, all in the Keuper Sandstone. Sea water has undoubtedly gained access to the stratum here. In Notts an abundance of good water is obtained from this formation, but in most cases both the temporary and permanent hardness are high, and sometimes the water contains an unusual amount of magnesium chloride, a not unimportant constituent if the water is to be used for boiler purposes. The Yorkshire waters from this formation also vary greatly, and possibly, by plotting these on the geological map, the cause of the variation could be discovered. None of them contains an unusual amount of common salt or magnesium chloride. Several of them are markedly ferruginous. Sections of most of these wells are given in the report of the Medical Officer of Health on the water supplies from the New Red Sandstone in the West Riding, 1903. No. 667 may be said to represent the normal unpolluted water from the sandstone at Crowle, Lincs. The deepening of this borehole (Nos. 669 and 670) gave a worse, and unusable, water. No. 668 from the public pump in the Market Place is highly nitrated, and shows in a remarkable degree the effect of the population living upon this pervious stratum.

No. 671 is from the celebrated Lincoln boring, undertaken under the direction of Mr. Percy Griffiths. No water was found until the marls were pierced at a depth of 1,561 feet. Water then rose and overflowed at the surface at the rate of 180,000 gallons per diem. The temperature of the water remained constant at 77° F. The sample examined was taken when the boring had reached 2,120 feet, and the boring was apparently stopped at 2,200 feet. To what extent the water may have varied at different depths is not known, but, six months after the examination of the first sample, the total solids had fallen from 410 to 222 parts per 100,000. Enough water was not received to make a very full analysis. In an analysis made still later (672) the total solids had fallen to 177. The Gainsborough bores (Nos. 673-676), which vary from 1,000 to 1,634 feet in depth, yield waters of a very different character, but the newer and deeper bores (Nos. 674-675) yield much better water, since they contain much less sulphate of calcium. In Staffordshire, a boring made to obtain a supply of potable water yielded a water containing a large quantity of calcium sulphate (No. 682). In the Potteries, the water from the sandstone contains little or no calcium sulphate.

Magnesian Limestone Waters (Nos. 693-697). The five analyses given seem fairly typical of waters from this formation, being rich in both calcium and magnesium salts.

Waters from The Coal Measures (Nos. 698-718). Here again an extraordinary variety of waters is obtained. Nearly all are hard, some excessively so. A number of samples were collected from used and disused coal mines in the Rochdale neighbourhood. Most of them were ferruginous, and a few excessively hard. Some were of excellent quality and suitable for all domestic purposes, and the softest contained sodium carbonate. Sodium carbonate may be present in appreciable amount, and these waters have also a high content of sodium chloride. With few exceptions, all the waters from the Coal Measures contained sodium sulphate, and the exceptions may possibly be Millstone Grit waters; one was from a spring in the Rhymney Valley, and another from the Severn Tunnel.

Nos. 710 to 714 are from coal mines in West Gloucestershire. One mine yields a most variable water, the hardness rising with the amount of water pumped. It is fairly certain that water derived from coal mines is a mixture of waters from all the pervious strata lying above the coal. This accounts for the great variability. It is noteworthy that when magnesium sulphate is absent, sodium sulphate is present in much larger quantity than in the waters in which magnesium sulphate is present. There is a clear indication of base exchange action substituting sodium for magnesium in the sulphate.

Millstone Grit Waters (Nos. 719-724). Nos. 719-721 are from borings, and the others are surface waters from this formation. Obviously this compact rock yields comparatively little saline matter to the water penetrating it; calcium carbonate is generally the chief constituent. A little sodium carbonate is present in the water from the deep bores. The water may contain traces of iron.

Carboniferous Limestone Waters (Nos. 725-737). The Trefil brook is fed by springs and surface-water from this formation. At one point in its course most of the water disappears through fissures, and this emerges as a spring (No. 726) about half a mile lower down the valley. In its course it appears to have taken up nothing from the rocks through which it has travelled. The waters from the Millstone Grit formation (Nos. 723-724) come from the opposite side of the valley and enter the Trefil brook just above the spring. The difference in the character of the brook waters from the two sides of the valley is marked.

The Pontypool water is derived from headings driven into the fissured limestone. The Bakewell water (No. 728) arises from a spring in this formation, but the temperature is said to be distinctly higher than that of other waters in the locality. It may therefore have its origin in an entirely different formation, which would account for the presence of the calcium and magnesium sulphates.

The waters from Ireland are all from wells of moderate depth.

Old Red Sandstone Waters (Nos. 738-741). No. 740 comes from a deep well in this formation. It is 376 feet deep, and the water overflows at the surface. A well is sunk through all the more superficial beds, 126 feet in thickness, and tubed into the sandstone. The sample

was taken from the bore-tube after the well had been pumped dry, so that it is, undoubtedly, derived entirely from this formation. It is a comparatively soft water of excellent character.

Waters from Older Rocks (Nos. 742-746). Note the resemblance between the Llandrindod water and that from the boring at Kelso. In making the Kelso boring a very good water was first obtained, but upon piercing the hard calciferous rock to a depth of 200 feet, highly saline water (No. 745) broke in and rendered the boring useless. A boring at Floor's Castle, near Kelso, in the same formation, yields an excellent water. The calcium and magnesium salts have practically disappeared, having been replaced by sodium salts. The result is a water of only 2 degrees of hardness.

Foreign Waters. (Nos. 747-790). The river and spring waters, Nos. 747-759, from various countries, are with one exception used for public supply purposes. No. 757 is a spring water bottled and sold for table use.

The public water supply to Aden, Arabia, is obtained from a number of boreholes, some of which are much deeper than others. The waters from two of these are shown in Nos. 760 and 761.

Nos. 762-768 are representative of boreholes in Irak, which provide supplies for communities in the oilfields and along the pipelines. Treatment plants are installed in some cases.

A series of waters obtained from boreholes in the Flanders area of Northern France and Belgium is shown in Nos. 769-788. The geological conditions in this region closely resemble those of the London Basin (see Nos. 136-295). In the centre is a thick bed of Ypresian Clay overlying layers of sand, principally the Landenien Sand. This sand is a glauconite (or zeolite)-bearing formation separating the clay from the chalk. These beds correspond respectively to the Lower London Tertiaries and Chalk of the London Basin. The sands and the chalk outcrop to the north, south and west, but to the east there are faults, and older formations, including the Coal Measures, are to be found. The analyses show that the character of the water is identical with that derived from the London Basin. Where the sands and chalk are covered by a thick bed of clay, the water is soft, and rich in sodium salts. The free ammonia content is similarly high, and the organic and bacterial purity is excellent. The water yielded by the Chalk at or near its outcrop (Nos. 785-788) resembles the so-called typical chalk waters of England. It is hard, the carbonates of calcium and magnesium comprising the greater part of its mineral constituents, sodium carbonate is absent, and the free ammonia content is low. The Landenien Sand softens this water by substitution of sodium for calcium and magnesium, *i.e.*, base-exchange, and laboratory experiments indicated that the Landenien Sand has greater softening power than Thanet Sand. Where the Chalk is still covered by some clay and sand, waters intermediate between the two groups of hard and soft waters are obtained (Nos. 774, 779, 780). The depths of the boreholes are given, and it will be seen that those terminating in the sands beneath the clay (Nos. 769-776) yield

the softest waters. These boreholes are, however, apt to become blocked with sand.

Nos. 789-790 are from deep borings in the Coal Measures: No. 789 closely resembles the Landenien Sand waters, and provides the public water supply to Armentières. No. 790, although soft, is quite unfit for consumption owing to its high content of sodium sulphate and chloride.

CHAPTER XXV

THE RESULTS OF ANALYSIS OF WATER FROM VARIOUS GEOLOGICAL SOURCES

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

SURFACE, LAKE AND RESERVOIR WATERS

Number Source	1	2	3	4	5	6	7	8	9	10	11
	Nr. Bury, Lancs.	Nr. Bury, Lancs.	Chesendon, Lancs.	Nr. Oldham, Lancs.	Nr. Oldham, Lancs.	Colwyn, N. Wales	Pontypool, Mon.	Nr. Wakefield, Yorks.	Aberdeen-shire	Tavistock, Devon	Liskeard, Cornwall
Ferrous Carbonate	Trace	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	.8	—	—	—	—	.9	1.4	.45	2.25	2.0	.4
Calcium Sulphate	3.2	3.9	2.2	4.3	9.35	—	—	3.1	1.0	.7	.34
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	.1	—	—	—	—
Magnesium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Sulphate	2.8	2.3	1.5	.25	.5	.25	.85	1.35	1.0	.25	.15
Magnesium Chloride	—	—	—	—	—	—	—	—	.8	—	.12
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	—	—	—	—	—	—	1.25	—	—	—	—
Sodium Chloride	1.8	2.15	2.5	2.15	2.5	1.3	2.0	1.8	2.3	3.3	2.0
Sodium Nitrate	.35	.4	.95	.4	1.4	.05	.05	.15	3.0	.75	—
Silica	3.45	2.5	.85	.3	.95	.3	.45	1.15	3.15	.5	.89
Organic Matter, etc.}											

Total	12.4	11.3	8.0	7.4	14.7	2.8	6.1	8.0	13.5	7.5	3.9
Total Hardness	6	6	3.5	5	10	1.5	2.5	4.5	5	4	1
Free Ammonia	.003	.002	.036	.002	—	.002	.0005	.005	.006	.002	.0000
Albuminoid Ammonia	.010	.012	.004	.005	—	.001	.0010	.012	.006	.005	.0028
Oxygen Absorbed*	.068	.084	.068	—	—	.015	.016	.060	.040	.045	.045

* 4 hours at 27°C.

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LAKE AND RESERVOIR WATERS

Number Source	12 Gransley, Northants.	13 Lake Embsdale	14 Longden- dale	15 Lake Thirlmere	16 Buxton	17 Loch Linthaven	18 Loch Katrine	19 Langsett, Sheffield	20 Llyn Trafwall	21 Llyn Llygad Rheidol	22 Cray, Brecknock
Ferrous Carbonate	—	.45	—	—	—	—	.3	—	—	—	—
Calcium Carbonate	16.0	.15	.4	.25	2.55	1.0	.25	—	5.0	.2	2.0
Calcium Sulphate	5.78	—	1.14	.34	—	—	—	1.53	1.7	1.09	.51
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	.6	.42	—	—	—	—	—
Magnesium Carbonate	—	—	—	—	—	.5	.45	1.63	2.7	—	.49
Magnesium Sulphate	2.72	—	1.0	.38	—	—	—	—	—	—	—
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	1.7	—	.74	.28	1.6	—	—	1.95	.22	1.38	1.02
Sodium Chloride	2.31	1.3	1.48	.99	1.2	.66	.8	1.48	7.25	1.16	1.24
Sodium Nitrate	.49	—	—	—	—	—	Trace	—	—	—	—
Silica	.3	.1	.5	.2	Trace	.5	1.5	.72	.8	.2	.2
Organic Matter, etc.	.7	.5	.54	.11	.25	1.92	1.5	.69	1.63	.47	.34
Total	30.0	2.5	5.8	2.5	6.2	5.0	3.3	8.0	19.3	4.5	5.8
Total Hardness	22.5	0.75	2	0.75	3.5	2	1	2.5	9	1	3
Free Ammonia	.0028	—	.0032	.0012	.003	.0064	—	.0216	.0080	.0000	.0000
Albuminoid Ammonia	.0176	—	.0066	.0028	.005	.0056	—	.0088	.0290	.0034	.0088
Oxygen Absorbed	.145	—	.125	.085	—	.280	—	.125	.425	.065	.110

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

STREAM AND RIVER WATERS

Number	23	24	25	26	27	28	29	30	31	32	33	34
Source	Stane, Devon	Swan- combe, Devon	Holyford, Devon	De Lank, Cornwall	Avon, Glouc, Wilts.	Cork	Liffey, Dublin	Montybella Stream, Wales	R. Cerlog, Wales	R. Dee, Wales	Dee, above Chester	Taff, Glam.
Ferrous Carbonate	—	—	—	—	—	Trace	—	—	—	—	—	—
Calcium Carbonate	.3	.35	3.5	.2	26.5	1.75	6.5	.275	.85	2.0	8.5	8.5
Calcium Sulphate	—	—	1.36	.41	—	—	—	—	.24	1.02	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	.18	.18	—	—	—	.05	—	.05	—	—	.4	4.6
Magnesium Sulphate	—	—	.74	.14	1.41	.55	1.0	.315	.49	.89	3.4	2.47
Magnesium Chloride	—	—	—	.36	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	.9	.75	—	—	7.1	.8	.74	.37	.13	.6	1.6	10.93
Sodium Chloride	1.65	1.65	4.12	1.7	3.3	2.8	1.32	1.98	1.49	1.98	3.6	2.47
Sodium Nitrate	—	—	.48	.42	.96	—	—	—	—	—	.1	1.23
Silica	.08	.12	.7	.45	.8	{		.35	.2	.4	{	
Organic Matter, etc.	1.69	1.55	.4	.32	.43	.15	3.94	.16	.6	1.6	.9	1.0
Total	4.8	4.6	11.3	4.0	40.5	6.1	14.0	3.5	4.0	8.5	18.5	32.0
Total Hardness	.75	.75	5	1	24	3	7	.5	1.5	3	12	16
Free Ammonia	.004	.002	.0018	.0032	.0032	.021	.0020	.0014	.0052	.0024	.0110	.090
Albuminoid Ammonia	.008	.009	.0064	.0072	.0104	.036	.0180	.0022	.0092	.0104	.0190	.014
Oxygen Absorbed	.090	.095	.130	.145	.125	.40	.350	.030	.125	.290	.245	1.30

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

RIVER WATERS

Number	35	36	37	38	39	40	41	42	43	44	45	46
Source	Avon, Hants.	Itchen, Hants.	New River	Thames, Slough	Thames, Staines	Thames, Grays	Lee, Brimsdown	Lee, West Ham	Chelmer, Essex	Black- water, Essex	Stour, Essex, Suffolk	Stour, Hants.
Ferrous Carbonate	—	—	—	—	—	—	Trace	—	—	—	—	—
Calcium Carbonate	17.5	23.3	15.3	18.0	19.8	16.3	22.5	23.75	25.0	24.55	23.0	23.2
Calcium Sulphate	.7	.7	—	4.95	4.0	71.4	6.8	10.05	3.4	3.1	.7	1.55
Calcium Chloride	—	1.1	—	—	.8	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Sulphate	1.0	—	2.0	1.65	—	129.5	2.75	5.5	1.9	3.15	3.45	.75
Magnesium Chloride	—	Trace	—	.6	1.6	154.8	—	1.2	—	—	—	.4
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	—	—	—	—	—	—	—	—	—	.45	2.3	—
						KCl: 41.0						
Sodium Chloride	2.55	2.95	3.0	2.55	4.9	391.0	5.1	5.1	4.6	6.9	5.6	2.8
Sodium Nitrate	1.5	1.85	.7	2.05	5.3	2.5	1.7	3.4	1.8	2.3	.6	2.1
Silica	—	—	—	—	—	—	{ 1.3	2.0	3.3	.55	.65	1.0
Organic Matter, etc.	1.25	1.1	.6	3.4	1.6	47.5	.45	—	—	—	—	—
Total	24.5	31.0	21.6	33.2	38.0	1,854.0	40.6	51.0	40.0	41.0	36.3	31.8
Total Hardness	19	24	16	22	26	—	28	36	30	30	28	24
Free Ammonia	.002	.006	.000	.010	.006	—	.016	.480	.014	.006	.007	.011
Albuminoid Ammonia	.009	.007	.007	.023	.007	—	.020	.066	.018	.018	.032	.019
Oxygen Absorbed	.085	.060	.100	.325	.128	—	.230	.60	.220	.148	.210	.245

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

STREAM AND RIVER WATERS

Number	Source	47	48	49	50	51	52	53	54	55	56
		Witham, above Lincoln	Welland, nr. Grantham	Bure, Norfolk	Ouse, Bedford	Windrush, Oxon.	Severn, Glos.	Wye, Glos.	Worfe, Staffs.	Ches., Bucks.	Newbourne Stream, Suffolk
Ferrous Carbonate		—	—	—	—	—	—	—	—	—	—
Calcium Carbonate		18.7	19.8	17.0	21.5	17.0	5.0	2.0	16.0	22.5	17.0
Calcium Sulphate		12.0	8.15	4.42	4.4	—	.85	1.36	3.4	1.7	4.08
Calcium Chloride		—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		—	—	—	—	—	—	—	—	—	—
Magnesium Sulphate		2.55	3.05	1.98	3.4	1.48	4.45	.59	5.45	.5	Trace
Magnesium Chloride		—	1.6	—	—	—	—	—	—	—	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	—	—	—	—	—	—	—	—	—
Sodium Sulphate		1.75	—	2.81	2.65	1.81	.52	.84	—	.6	—
Sodium Chloride		3.5	2.65	17.49	4.5	1.65	3.46	1.32	5.45	2.6	4.3
Sodium Nitrate		.2	1.2	—	.6	1.45	.85	—	1.7	1.78	2.47
Silica		.7	.55	1.8	.35	{ 1.1 1.1 .51 }	.9	.4	.95	1.0	1.1
Organic Matter, etc.		—	—	—	—	—	1.27	.49	1.55	1.32	1.05
Total		39.4	37.0	45.5	37.4	25.0	17.3	7.0	34.5	32.0	30.0
Total Hardness		29	28	22	27.5	18	9.5	3.5	23	24.0	20
Free Ammonia		.001	.006	.0034	.0064	.0056	.0200	.0032	.0056	.0080	.004
Albuminoid Ammonia		.010	.020	.0230	.0234	.0084	.0380	.0180	.0192	.0064	.017
Oxygen Absorbed		.070	.174	.235	.221	.100	.430	.270	.230	.115	.230

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

STREAM AND RIVER WATERS

Number	57	58	59	60	61	62	63	64	65	66
Source	Mole, Surrey	Caterham Bourne, Surrey	Colne, Herts.	Tees, Yorks.	Little Avon, Glos.	Otter, Somerset	Usk, Brecknock	Kennet, Berks.	Road, Lancs.	Mullingar Stream, Ireland
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	12.7	23.5	24.5	3.0	22.5	3.5	5.87	16.5	10.25	39.7
Calcium Sulphate	4.7	5.1	4.1	—	5.1	—	—	1.7	—	—
Calcium Chloride	—	.8	—	—	—	—	—	—	—	—
Calcium Nitrate	—	3.28	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	—	.51	—	—	.53	—	4.01	1.12
Magnesium Sulphate	3.63	—	—	2.7	1.73	1.09	—	.49	1.43	.88
Magnesium Chloride	1.37	.31	1.17	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	.49	1.78	1.2	22.0	3.4
Sodium Sulphate	—	—	—	—	1.52	1.98	1.32	2.15	11.9	3.2
Sodium Chloride	1.3	3.58	2.53	.99	3.3	—	—	1.1	1.33	2.43
Sodium Nitrate	1.6	—	2.47	—	.85	.25	—	.9	1.35	.95
Silica	1.0	1.3	1.3	.25	1.2	.35	.35	.46	2.23	.32
Organic Matter, etc.	.6	.63	2.93	1.35	1.3	.34	.45	—	—	—
Total	26.9	38.5	39.0	8.8	37.5	8.0	10.3	24.5	54.5	52.0
Total Hardness	22	30	28	4	28	4.5	6	18	16	41
Free Ammonia	.0368	—	.0480	.0016	.0048	.0040	.0000	.0032	1.150	.0018
Albuminoid Ammonia	.0180	—	.0120	.0120	.0128	.0076	.0032	.0120	.065	.0095
Oxygen Absorbed	.200	.065	.125	.580	.190	.100	.030	.165	.770	.286

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

SPRING WATERS

Number	Source	67	68	69	70	71	72	73	74	75	76	77	78
		Stone, Bucks.	Hornchurch, Essex	Danbury, Essex	Torquay, Devon	Lyme Regis, Dorset	Lyme Regis, Dorset	Richmond, Surrey	Oxted, Surrey	Woolmer Park, Herts.	Hoddesdon, Herts.	Church Stretton, Salop.	Bedford, Beds.
Ferrous Carbonate		—	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate		21.5	24.5	2.0	27.7	8.0	22.0	5.5	7.0	23.5	5.5	3.25	30.0
Calcium Sulphate		14.74	17.0	5.1	—	1.02	3.06	16.3	1.4	3.77	7.82	—	25.5
Calcium Chloride		—	—	—	—	—	—	—	.55	2.6	—	—	—
Calcium Nitrate		3.73	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		—	—	—	8.28	—	—	—	—	—	—	.21	—
Magnesium Sulphate		—	2.76	2.25	16.92	.98	—	6.4	—	—	1.48	.7	13.3
Magnesium Chloride		—	—	1.75	6.25	—	1.9	3.9	—	.39	—	—	—
Magnesium Nitrate		1.95	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate		—	1.48	—	—	—	—	—	—	—	—	—	—
Sodium Chloride		5.61	7.9	2.47	12.85	3.8	2.81	4.0	2.72	.58	2.81	1.53	3.5
Sodium Nitrate		3.42	3.56	4.4	1.7	.25	2.55	2.47	2.46	1.95	4.38	.96	5.6
Silica		.9	1.3	1.2	1.3	1.3	1.2	1.0	.8	1.3	.95	.6	1.2
Organic Matter, etc.		.15	.9	1.33	.1	.65	.48	.43	—	.11	.06	.11	.8
													1.1

Total	52.0	59.4	20.5	75.0	16.0	34.0	40.0	15.0	34.2	23.0	9.5	81.0
Total Hardness	37	40	10	62.5	9	25.5	28	8	28	12.5	4	58
Free Ammonia	.0024	.0080	.0020	.0004	.0018	.0026	.0044	.0018	.0000	.0004	.0000	.0044
Albuminoid Ammonia	.0048	.0012	.0016	.0008	.0110	.0010	.0180	.0004	.0000	.0008	.0000	.0054
Oxygen Absorbed	.060	.010	.020	.010	.160	.010	.245	.005	.020	.015	.000	.061

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

SPRING WATERS

Number	79	80	81	82	83	84	85	86	87	88	89	90
Source	Braunton, Lincs.	Oxford	Sibford, Oxon.	Hastings, Sussex	Battle, Sussex	Upway, Dorset	Tunbridge Wells, Kent	St. Agnes, Cornwall	Weston- super-Mare, Somerset	Bakewell, Derby	Rillington, Yorks.	Berwick- on-Tweed, N.B.
Ferrous Carbonate	—	—	—	1.75-	—	—	—	—	—	—	—	—
Calcium Carbonate	18.0	2.0	13.5	10.0	11.5	17.5	.8	1.0	16.0	.75	15.5	8.0
Calcium Sulphate	1.36	7.79	2.04	4.42	2.72	1.36	1.56	1.36	—	.68	6.8	—
Calcium Chloride	—	2.52	—	—	—	—	.89	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	.41	—
Magnesium Carbonate	—	—	—	—	—	—	—	—	2.95	—	—	2.53
Magnesium Sulphate	1.33	—	.99	2.47	2.36	.49	—	1.63	.25	.75	—	9.27
Magnesium Chloride	—	.12	—	—	2.23	—	2.35	1.33	—	—	.47	1.56
Magnesium Nitrate	—	1.04	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	MnSO ₄ .39	—	—	—	—	—	—	—	—
Sodium Sulphate	1.75	—	1.14	2.46	—	—	—	—	2.66	.77	—	—
Sodium Chloride	3.14	—	1.82	11.22	6.01	3.47	3.1	4.47	2.31	1.98	2.39	4.19
Sodium Nitrate	2.46	4.29	1.7	—	1.96	1.45	2.74	1.58	.85	.24	2.25	3.02
Silica	1.0	2.2	1.0	1.8	1.3	1.2	1.1	.85	.6	.5	.75	1.1
Organic Matter, etc.	.46	.04	.31	.49	.92	.53	.46	.78	1.38	.33	.93	.83
Total	29.5	20.0	22.5	35.0	29.0	26.0	13.0	13.0	27.0	6.0	29.5	30.5
Total Hardness	20.5	11	16	17	18	19	5.5	5	20	2	21	21
Free Ammonia	.0016	.0026	.0016	.0150	.0016	.0026	.0018	.0000	.0016	.0008	.0004	.0000
Albuminoid Ammonia	.0084	.0020	.0008	.0020	.0008	.0004	.0008	.0000	.0008	.0024	.0000	.0000
Oxygen Absorbed	.100	.030	.015	.170	.015	.010	.010	.010	.015	.130	.005	.000

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

SHALLOW WELLS

Number	91	92	93	94	95	96	97	98	99	100	101
Source	Tiptree, Essex	Lexden, Essex	Chelms- ford, Essex	Felsted, Essex	Kelvedon, Essex	Danbury, Essex	South- minster, Essex	Woodham Walter, Essex	Great Waltham, Essex	Great Baddow, Essex	East Ham, Essex
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	5.0	2.5	30.0	33.3	17.5	2.5	1.0	5.5	27.7	4.0	70.0
Calcium Sulphate	2.7	3.0	5.4	12.3	8.5	5.95	3.4	2.4	10.2	10.2	25.2
Calcium Chloride	—	4.4	—	2.4	—	.95	3.0	—	2.5	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Sulphate	1.0	—	2.9	—	2.5	—	—	1.0	—	.75	26.5
Magnesium Chloride	.8	1.7	1.3	2.7	—	2.15	2.3	.8	1.1	3.35	22.7
Magnesium Nitrate	—	3.6	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	—	—	—	—	—	—	—	—	—	—	—
Sodium Chloride	2.5	—	3.9	3.1	5.4	.65	—	2.15	—	1.5	181.5
Sodium Nitrate	3.95	3.0	4.9	4.9	5.7	4.8	8.5	2.75	4.8	6.7	—
Silica	.55	.8	.6	1.3	.4	.5	3	.4	.7	.3	.6
Organic Matter, etc. }											
Total	16.5	19.0	49.0	60.0	40.0	17.5	18.5	15.0	47.0	26.8	326.5
Total Hardness	8.5	13.5	36	44	23	10	12	10	38	18	150
Free Ammonia	.002	.001	.001	.000	1.12	.001	.004	.001	.000	.001	Excessive
Albuminoid Ammonia	.010	.002	.006	.003	.007	.002	.002	.002	.002	.002	"
Oxygen Absorbed	.052	.027	.028	.028	.063	.020	.016	.016	.020	.020	—

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
SHALLOW WELLS, 102-108. BOULDER CLAY WATERS, 109-111

Number	102	103	104	105	106	107	108	109	110	111
Source	Millwall, London	Selly Isles	Toines, Devon	Raydon, Suffolk	Castlethorpe, Bucks.	Tunstall, Staffs.	Holyhead, Anglesey	S. Hamming- field, Essex	Great Waltham, Essex	Epping field, Essex
Ferrous Carbonate	13.1	—	—	—	—	—	—	—	—	—
Calcium Carbonate	39.7	2.0	2.0	10.0	29.0	6.5	8.5	23.4	34.5	15.5
Calcium Sulphate	49.0	9.18	—	5.44	11.22	45.34	17.68	17.6	—	12.95
Calcium Chloride	.8	—	—	—	—	3.39	—	14.1	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	1.05	—	—	—	—	—	.85	—
Magnesium Sulphate	—	5.42	—	.7	2.96	—	.4	—	8.25	—
Magnesium Chloride	66.5	7.43	—	.23	—	.63	5.55	11.5	—	4.2
Magnesium Nitrate	—	—	—	—	—	.55	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	334.6	29.16	2.05	—	3.42	—	—	—	7.55	—
Sodium Nitrate	—	9.12	1.65	4.01	4.79	—	7.71	24.6	3.65	1.15
Silica	—	1.2	.4	4.39	3.88	2.74	9.12	3.7	1.25	7.5
Organic Matter, etc.	6.3	{ 1.99	1.35	.53	.93	1.1	.85	3.1	1.95	.7
Total	510.0	65.5	8.5	26.5	57.0	61.5	51.5	98.0	58.0	42.0
Total Hardness	130	22	3.5	15	40	44	28	64	42	30
Free Ammonia	Excessive	.0006	.0330	.0128	.0036	.0108	.0220	.004	.016	.000
Aluminoid Ammonia	.018	.0320	.0062	.0092	.0004	.0140	.0052	.014	.008	.004
Oxygen Absorbed	—	.350	.160	.140	.005	.165	.065	.240	.202*	—

* Strong smell of H₂S.

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

POST-TERTIARY GRAVELS AND SANDS

Number	Source	112	113	114	115	116	117	118	119	120	121	122	123
		Tonbridge, Kent	Tonbridge, Wells, Kent	Richmond, Surrey	Broomfield, Essex	Tollesbury, Essex	Copfold, Essex	Clacton, Essex	Great Bentley, Essex	Coggeshall, Essex	Longham, Hants.	Lutter- worth, Leics.	Brigg, Lincs.
		—	—	—	—	—	ZnCO ₃ : 21	—	—	—	—	—	—
Ferrous Carbonate		17.2	.5	16.0	20.5	14.0	28.8	6.5	2.5	29.3	22.05	27.6	20.0
Calcium Carbonate		5.8	1.84	12.2	54.5	31.3	2.6	5.4	8.8	2.05	2.4	12.9	14.74
Calcium Chloride		—	.44	—	24.1	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	4.9	—	—	—	—	—	—	—	3.53
Magnesium Carbonate		—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Sulphate		4.0	—	1.75	—	5.5	3.5	6.5	3.75	3.75	.4	.65	—
Magnesium Chloride		—	1.8	.78	—	7.5	—	—	1.7	—	—	1.85	1.96
Magnesium Nitrate		—	—	—	18.5	—	—	—	—	—	—	—	—
Sodium Carbonate		—	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate		—	—	—	—	—	—	2.7	—	5.0	—	—	—
Sodium Chloride		6.1	2.28	4.65	—	17.5	5.3	12.5	4.3	5.1	2.1	1.35	3.37
Sodium Nitrate		1.7	2.88	7.0	45.5	22.8	1.65	5.4	5.6	4.9	2.1	3.4	2.41
Silica		2.2	1.06	1.62	6.15	4.7	1.75	3.0	.35	.4	.5	.35	1.99
Organic Matter, etc. }													
Total		37.0	10.8	44.0	180.0	120.3	45.7	42.0	27.0	50.0	30.5	48.1	48.0
Total Hardness		26	4	27.5	105	50	27	16	16	33	25	42	35
Free Ammonia		.001	.0024	.0012	.012	.000	.000	.003	.001	.000	.002	.001	.0032
Albuminoid Ammonia		.004	.0028	.0036	.035	.013	.011	.004	.006	.005	.007	.006	.0028
Oxygen Absorbed		.030	.035	.045	.40	.173	.064	.032	.036	.008	.081	.020	.035

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LOWER LONDON TERTIARIES. DEEP WELLS IN ESSEX

Number Source	136 Tollesbury, 187 ft.	137 Tollesbury, 236 ft.	138 Burnham	139 Althorne	140 Mundon	141 Foulness Island	142 Foulness Island	143 Mersea Island	144 Mersea Island	145 Heybridge, 1900	146 Heybridge, 1908
Ferrous Carbonate	—	Trace	—	—	—	—	—	—	—	—	—
Calcium Carbonate	5.25	4.25	3.25	29.3	3.0	2.15	10.25	4.5	39.0	3.25	9.0
Calcium Sulphate	—	—	—	7.6	—	—	—	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	2.15	1.95	2.75	—	1.4	1.0	6.9	1.05	4.55	1.9	5.5
Magnesium Sulphate	—	—	—	42.5	—	—	—	—	32.0	—	—
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	32.45	35.9	32.7	—	37.1	30.1	14.95	33.85	—	34.75	25.1
Sodium Sulphate	40.5	12.1	9.4	59.2	12.0	10.8	18.95	23.1	15.7	16.3	16.8
Sodium Chloride	118.9	123.7	61.5	49.3	62.0	75.0	141.5	128.0	54.9	69.8	128.8
Sodium Nitrate	—	—	—	.9	—	—	.85	—	—	—	—
Silica	.75	1.1	.4	1.2	.5	.95	.6	.5	{ Much organic matter 9.95 }		.8
Organic Matter, etc.										1.5	
Total	200.0	179.0	110.0	190.0	116.0	120.0	194.0	191.0	156.3	127.5	186.0
Total Hardness											
Free Ammonia	8	7	6	70	4.5	3.5	19	7	70	5	16
Albuminoid Ammonia	.145	.120	.050	.003	.040	.040	.010	.015	.012	.056	.120
Oxygen Absorbed	.004	.006	.002	.008	.003	.002	.003	.004	.028	.002	.004
	.252	.236	.043	.140	.055	.064	.040	.064	.209	.088	.092

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LOWER LONDON TERTIARIES. DEEP WELLS IN ESSEX

Number Source	147 Heybridge, 1009	148 Heybridge Hall	149 Maldon	150 Maldon	151 Maldon	152 Writtle	153 Broom- field	154 Chelmsford	155 Shoebury- ness	156 Canewdon	157 Abberton
Ferrous Carbonate	—	1.0	—	—	—	—	—	—	—	—	—
Calcium Carbonate	6.3	6.9	1.75	2.5	15.25	2.0	1.8	2.0	1.7	1.5	16.85
Calcium Sulphate	—	—	—	—	—	—	—	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	3.8	5.25	2.1	1.8	6.3	.5	1.05	1.75	.85	1.75	4.75
Magnesium Sulphate	—	—	—	—	—	—	—	—	—	—	11.5
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	17.6	28.75	37.4	36.3	11.75	32.65	35.0	31.4	27.8	32.6	—
Sodium Sulphate	11.8	19.25	15.0	7.7	18.95	13.6	8.9	14.2	8.3	11.1	208.4
Sodium Chloride	90.2	155.1	60.0	83.1	71.45	45.85	56.4	54.8	55.1	56.9	136.0
Sodium Nitrate	—	—	—	—	4.8	—	—	—	—	—	—
Silica	.6	1.15	2.75	1.1	2.0	1.9	1.35	.85	.75	2.15	.5
Organic Matter, etc. }											
Total	130.3	217.4	119.0	132.0	130.0	96.5	104.5	105.0	94.5	106.0	378.0
Total Hardness	11	13	4	5	23	3	3	4	3	3.5	—
Free Ammonia	.025	.120	.010	.066	.012	.000	.080	.065	.000	.084	—
Albuminoid Ammonia	.003	.002	.002	.003	.010	.004	.001	.002	.003	.010	—
Oxygen Absorbed	.050	—	—	.028	.055	.045	.048	.160	.040	.056	—

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LOWER LONDON TERTIARIES. DEEP WELLS IN ESSEX AND KENT

Number	158	159	160	161	162	163	164	165	166	167	168
Source	Great Sailing	Waltham Abbey	Osea Island	Braintree	Bulphan	Ingatestone	Chelmsford	Maldon	Eastchurch, Kent, 725 ft.	Minster, Kent, 500 ft.	Minster, Kent, 600 ft.
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	5.9	9.5	7.9	1.85	29.3	2.2	2.25	3.2	1.0	28.25	2.0
Calcium Sulphate	—	44.2	—	—	114.9	—	—	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	5.2	—	3.85	1.55	—	1.05	1.75	1.7	.28	6.53	.52
Magnesium Sulphate	—	44.4	—	—	362.5	—	—	—	—	12.94	—
Magnesium Chloride	—	—	—	—	45.5	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	16.4	—	23.35	28.5	—	29.45	33.45	36.5	19.8	—	22.13
Sodium Sulphate	10.2	99.5	17.3	26.3	—	8.6	10.05	8.7	19.7	1.6	20.7
Sodium Chloride	37.4	42.2	50.5	35.6	231.0	38.4	61.7	80.1	14.2	8.09	11.9
Sodium Nitrate	—	.6	—	—	1.5	—	—	—	—	—	—
Silica	—	—	—	—	—	—	—	—	—	—	—
Organic Matter, etc. }	.9	2.6	1.6	1.2	33.3*	.3	.8	1.8	{ 1.2	1.1	1.8
									{ 1.82	.99	.95
Total	76.0	243.0	104.5	95.0	818.0	80.0	110.0	132.0	58.0	59.5	60.0

Total Hardness	12.5	85	12.5	5	—	4	4	6	1	48	2.5
Free Ammonia	.016	.002	.080	.080	.002	.040	.075	.036	.0024	.0680	.0240
Albuminoid Ammonia	.001	.016	.012	.004	.003	.001	.001	.003	.0016	.0024	.0030
Oxygen Absorbed	.035	.075	.124	.060	—	.040	.032	.050	.035	.080	.040

* Water of hydration, etc.

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS IN ESSEX

Number	169	170	171	172	173	174	175	176	177	178	179	180
Source	Maldon	Oggeshall	Braintree	Bocking	Colchester	Earl's Colne	South Benfleet	Pitsea	Shoebury	Upminster	Rainham	Stratford
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	3.5	5.5	5.0	21.25	4.75	17.5	2.15	1.8	2.35	2.75	25.5	180
Calcium Sulphate	—	—	—	—	—	—	—	—	—	—	23.9	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	14.7	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	1.55	5.5	5.5	4.4	5.55	10.4	.9	.5	2.4	1.25	—	5.9
Magnesium Sulphate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	30.1	—
Sodium Carbonate	44.4	22.7	20.2	3.1	21.05	3.7	27.7	28.6	24.9	24.65	—	2.1
Sodium Sulphate	9.8	12.6	12.0	9.0	14.2	1.05	11.8	4.15	8.3	9.9	—	7.4
Sodium Chloride	70.0	75.4	69.2	28.05	102.25	5.9	45.2	38.45	54.1	29.5	120.7	6.1
Sodium Nitrate	—	—	—	—	—	—	—	—	—	—	—	.35
Silica	1.25	{ 2.0 1.3 }	.1	1.2	.2	.45	.75	1.0	1.45	.45	2.1	.45
Organic Matter, etc.	—	—	—	—	—	—	—	—	—	—	—	—
Total	130.5	125.0	112.0	67.0	148.0	39.0	88.5	74.0	93.5	68.5	217.0	35.0
Total Hardness	6.5	12	11	26	11	30	4	2.5	5.5	6	95	20
Free Ammonia	.085	.020	.112	.057	.104	.068	.025	.045	.032	.066	.140	.031
Albuminoid Ammonia	.002	.001	.006	.003	.004	.004	.002	.004	.001	.000	.003	.001
Oxygen Absorbed	.075	.036	.038	.046	.008	.081	.042	.085	.016	.040	.060	.028

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS IN ESSEX.

Number	181	182	183	184	185	186	187	188	189	190	191	192
Source.	Ilford	Ilford	Waltham- stow	Waltham- stow	East Ham	East Ham	Barking	Leyton	Leyton	Waltham Abbey	Waltham Abbey	Stansted
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—	Trace
Calcium Carbonate	10.0	7.5	20.8	8.7	11.7	25.5	8.75	12.7	14.0	2.5	15.2	26.0
Calcium Sulphate	—	—	8.2	—	—	16.6	—	—	—	—	—	3.0
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—	2.2
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	4.1	5.4	—	5.9	6.2	—	5.9	6.2	4.8	1.9	8.6	—
Magnesium Sulphate	—	—	3.4	—	—	7.4	—	2.0	—	—	—	—
Magnesium Chloride	—	—	—	—	—	6.2	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	1.1
Sodium Carbonate	8.3	14.1	—	6.0	4.9	—	8.25	—	1.6	27.85	1.8	—
Sodium Sulphate	14.2	20.5	—	6.1	5.5	—	10.9	8.7	7.1	17.5	15.3	—
Sodium Chloride	4.9	12.8	4.3	4.0	5.0	65.0	13.0	5.4	4.4	17.8	5.6	15
Sodium Nitrate	.35	1.5	2.2	1.5	.7	.9	.75	.25	.25	—	—	5.0
Silica	.15	1.2	.6	.8	.3	2.6	.45	.75	.85	1.45	.5	.55
Organic Matter, etc. }												

Total	42.0	63.0	39.5	33.0	34.3	124.2	48.0	36.0	33.0	69.0	47.0	38.0
Total Hardness	16	14	32	16	20	54	18	25	20	4.5	26	30
Free Ammonia	.000	.094	.001	.080	.055	.008	.064	.020	.052	.084	.050	.002
Albuminoid Ammonia	.003	.001	.004	.001	.002	.006	.001	.001	.003	.004	.006	.011
Oxygen Absorbed	.029	.006	.100	—	.015	.040	.028	.030	.048	.100	.066	—

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS IN ESSEX

Number Source	193 Epping	194 Dunmow	195 Halstead	196 Dedham	197 Great Bentley	198 Brightling- sea	199 Wivenhoe	200 Wivenhoe	201 Shelhaven, Bore 1	202 Shelhaven, Bore 2	203 Abberton, 250 ft.	204 Bulphan
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	9.35	26.0	25.25	17.75	6.0	8.75	7.2	5.25	4.5	3.25	5.0	3.2
Calcium Sulphate	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	4.55	4.1	2.35	9.65	2.4	6.9	5.9	5.75	6.6	5.0	5.2	.83
Magnesium Sulphate	—	5.4	2.9	1.6	—	—	—	—	—	—	—	—
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	16.7	—	—	—	19.8	15.15	18.2	19.05	10.8	15.2	23.1	22.64
Sodium Sulphate	31.95	5.0	—	8.2	2.8	5.2	14.2	16.0	19.9	18.1	14.8	21.46
Sodium Chloride	12.2	8.9	14.2	44.05	4.0	25.9	70.9	117.0	39.7	19.0	89.1	9.08
Sodium Nitrate	1.65	.4	.35	—	—	—	—	—	—	—	—	—
Silica	.6	1.2	.95	.35	1.0	1.1	0.6	1.95	2.2	2.45	1.8	1.03
Organic Matter, etc.	—	—	—	—	—	—	—	—	—	—	—	—
Total	77.0	51.0	46.0	81.6	36.0	63.0	117.0	165.0	83.7	63.0	139.0	58.5
Total Hardness	15	35	30	32	9	17	.15	12.5	13.0	9.5	11	4
Free Ammonia	.000	.024	.016	.056	.001	.000	.004	.100	.056	.063	.064	.080
Albuminoid Ammonia	.006	.002	.001	.003	.005	.003	.001	.004	.001	.003	.004	.004
Oxygen Absorbed	.064	.025	.012	.028	.068	.029	.032	.036	.015	.008	.040	.290

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS IN ESSEX

Number Source	205 Southend	206 Holhaven	207 Dagenham	208 Dagenham	209 Dagenham 445 ft.	210 Goodmayes	211 Ilford	212 Brentwood, 700 ft.	213 Mar- garettling	214 Witham	215 Dagenham	216 Mistley
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	2.0	2.5	19.75	13.0	31.5	3.0	4.37	1.75	1.75	3.5	26.25	6.5
Calcium Sulphate	—	—	—	—	1.0	—	—	—	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	.85	3.5	7.2	10.3	—	3.18	5.53	.7	.52	1.4	1.05	8.3
Magnesium Sulphate	—	—	6.27	—	6.65	—	—	—	—	—	6.7	—
Magnesium Chloride	—	—	2.66	—	9.95	—	—	—	—	—	9.0	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	22.3	18.4	—	.88	—	20.43	13.85	28.05	36.78	26.3	—	11.3
Sodium Sulphate	11.1	8.7	—	7.4	—	21.46	17.76	14.2	10.36	18.6	—	19.0
Sodium Chloride	52.8	56.0	21.82	7.75	43.1	18.15	11.22	24.1	40.4	74.6	37.8	47.3
Sodium Nitrate	—	—	—	.55	.35	—	—	—	—	—	—	—
Silica	1.2	1.2	1.5	1.2	1.7	1.2	1.2	1.2	1.5	1.5	1.8	1.5
Organic Matter, etc.	1.75	.7	1.8	.2	1.05	.08	.67	—	1.69	2.1	.4	2.1
Total	92.0	91.0	61.0	41.3	95.3	67.5	54.6	70.0	93.0	128.0	82.0	96.0
Total Hardness	3	7	40	26	49	7	11	2.5	2.5	5	44	16.5
Free Ammonia	.041	.084	.105	.089	.104	.064	.060	.037	.025	.085	.096	.105
Albuminoid Ammonia	.004	.002	.003	.002	.008	.001	.001	.004	.033	.002	.003	.001
Oxygen Absorbed	.230	.026	.050	.025	.125	.015	.005	.060	.260	.035	.165	.020

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK UNDER LOWER LONDON TERTIARIES. LONDON DEEP WELLS

Number	217	218	219	220	221	222	223	224	225	226	227	228
Source	Leadonhall Street, E.C.*	Leadonhall Street, E.C.	Lombard Street, E.C., 700 ft.	Threagneedle Street, E.C.	Lofbury, E.C.	Gresham Street, E.C.	Princes Street, E.C.	Cornhill, E.C.	King William Street, E.C.	Poultry, E.C.	Throgmorton Street, E.C., 700 ft.	Moorgate, E.C.
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	40.5	6.25	3.38	5.25	4.5	3.0	5.6	4.37	4.0	3.5	4.4	3.12
Calcium Sulphate	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	8.0	4.5	3.29	3.46	2.95	3.46	4.15	3.46	3.46	3.73	3.8	2.07
Magnesium Sulphate	28.1	—	—	—	—	—	—	—	—	—	—	—
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	14.25	18.82	17.19	18.0	16.34	19.6	18.62	16.84	15.45	18.2	19.06
Sodium Sulphate	2.36	22.2	25.9	22.5	23.6	21.6	22.2	24.5	23.7	25.75	16.6	22.9
Sodium Chloride	23.8	20.4	19.8	20.1	18.9	18.1	20.1	20.8	19.1	18.8	17.3	17.7
Sodium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Silica	1.5	1.2	1.0	1.5	1.0	1.6	1.1	1.7	1.8	1.2	1.8	1.4
Organic Matter, etc.	1.74	1.2	.31	.5	.24	.9	.25	.55	1.1	.57	1.5	.78

Total	106.0	70.0	72.5	70.5	69.2	65.0	73.0	74.0	70.0	69.0	63.6	67.0
Total Hardness	74	13	7.5	9	8	7	10	9	8.5	8	9.5	6
Free Ammonia	.0800	.0410	.0570	.0710	.0370	.0340	.0510	.0540	.0470	.0390	.0372	.0560
Albuminoid Ammonia	.0160	.0016	.0032	.0010	.0016	.0008	.0010	.0008	.0016	.0020	.0052	.0017
Oxygen Absorbed	.100	.040	.050	.030	.025	.010	.010	.010	.050	.045	.215	.024

* 150 ft. in London clay.

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK UNDER LOWER LONDON TERTIARIES. LONDON DEEP WELLS													
Number	Source	229	230	231	232	233	234	235	236	237	238	239	240
		Finsbury, E.C.	Blackfriars, E.C.	King Street, E.C.	Trinity Square, E.C.	Tower Hill, E.C.	Nr. London Bridge, E.C.	City Road, E.C.	Farringdon Street, E.C.	Aldwych, W.C.	Holborn, W.C.	Strand, W.C.	Shaftesbury Avenue, W.C.
Ferrous Carbonate		—	—	—	—	.03	—	—	—	—	—	—	—
Calcium Carbonate		3.75	3.5	3.75	4.55	3.85	3.75	5.6	3.55	3.75	2.5	3.05	4.0
Calcium Sulphate		—	—	—	—	—	—	—	—	—	—	—	—
Calcium Chloride		—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		2.75	3.1	2.69	1.9	2.1	3.15	2.25	1.95	3.1	4.2	3.63	2.5
Magnesium Sulphate		—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Chloride		—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		17.53	17.8	18.64	19.35	20.55	18.9	18.5	21.75	18.15	18.0	17.22	18.4
Sodium Sulphate		23.68	23.7	22.2	21.9	20.7	25.6	20.7	20.1	24.7	20.2	23.6	24.8
Sodium Chloride		17.0	21.5	19.1	18.5	18.3	19.6	15.2	18.8	23.4	24.1	24.4	30.3
Sodium Nitrate		—	—	—	—	—	—	—	—	—	—	.8	—
Silica		1.8	1.8	1.1	1.3	1.2	1.3	{ .85 {		1.6	1.0	1.4	1.1
Organic Matter, etc.		1.05	1.2	.52	1.3	.8	.7		1.35	.3	.3	.9	.5

Total Hardness	7	7.5	7	7	7	6.5	7.25	8	7	7.5	7.5	7.5	8
Free Ammonia	.0470	.0570	.0540	.0516	.0516	.0880	.0660	.0450	.0520	.0580	.0550	.0460	.0820
Aluminoid Ammonia	.0016	.0052	.0012	.0002	.0060	.0060	.0030	.0030	.0010	.0024	.0004	.0032	.0010
Oxygen Absorbed	.025	.075	.030	.026	.068	.068	.010	.016	.022	.035	.025	.041	.180

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
CHALK UNDER LOWER LONDON TERTIARIES. LONDON DEEP WELLS

Number	Source	241	242	243	244	245	246	247	248	249	250	251	252
		Kingway, W.C.	Great George Street, S.W.	Millbank, S.W.	St. James's Park, S.W.	Fulham, S.W.	Tooting, S.W.	Streatham, S.W.	Victoria Street, S.W.	Wimbledon, S.W.	King's Cross, N.	Caledonian Road, N.	Tottenham, N.
Ferrous Carbonate		—	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate		3.5	3.15	4.0	5.75	1.9	16.5	21.0	7.8	10.5	3.5	4.0	14.0
Calcium Sulphate		—	—	—	—	—	3.06	2.04	—	—	—	—	—
Calcium Chloride		—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		1.05	2.3	3.1	2.75	2.42	—	—	4.5	5.19	.35	2.8	8.57
Magnesium Sulphate		—	—	—	—	—	1.93	.5	—	—	—	—	1.63
Magnesium Chloride		—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		22.35	19.75	21.6	16.2	19.89	—	—	17.3	5.68	23.55	19.1	—
Sodium Sulphate		26.15	28.4	16.3	21.0	10.36	—	1.13	18.2	4.59	19.5	20.0	10.9
Sodium Chloride		23.55	22.3	15.5	22.6	13.37	3.46	2.64	24.1	2.97	15.1	16.7	4.95
Sodium Nitrate		—	—	—	—	.48	1.34	1.1	—	—	—	—	.6
Silica		1.4	1.8	{ 1.2	1.4	1.3	1.7	1.2	1.5	1.3	.8	1.0	.6
Organic Matter, etc.		—	—	{ .3	—	.28	1.0	1.39	1.2	1.27	—	—	—
Total		78.7	77.7	62.0	69.7	50.0	29.0	31.0	74.6	31.5	62.8	63.6	41.3
Total Hardness		6.5	6	7	8	5	18	23	13.5	18	5.5	7	26
Free Ammonia		.0700	.0760	.0570	.0800	.0036	.0020	.0010	.0560	.1050	.0610	.0450	.0460
Albuminoid Ammonia		.0050	.0014	.0016	.0034	.0008	.0042	.0006	.0016	.0008	.0030	.0030	.0008
Oxygen Absorbed		.040	.009	.020	.030	.010	.080	.010	.040	.010	.007	.017	.015

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
CHALK UNDER LOWER LONDON TERTIARIES, LONDON DEEP WELLS

Number Source	253 Ken Wood, N.	254 Bernond- sey, S.E.	255 Bernond- sey, S.E.	256 Lambeth, S.E.	257 Sydenham, S.E.	258 Peckham, S.E.	259 Canberwell, S.E.	260 Leicester Square, W.	261 Piccadilly, W.	262 Bond Street, W.	263 Brook Street, W.	264 Soho, W.
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	4.0	33.75	13.3	12.75	25.0	22.25	30.5	4.37	5.55	2.25	3.75	5.0
Calcium Sulphate	—	—	—	—	2.38	—	17.68	—	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	3.46	6.4	10.0	7.85	—	2.3	—	2.67	3.1	2.75	2.45	1.04
Magnesium Sulphate	—	20.95	—	—	1.28	3.38	7.9	—	—	—	—	—
Magnesium Chloride	—	—	—	—	.55	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	21.14	—	11.0	6.9	—	—	—	18.55	16.15	20.7	19.47	18.86
Sodium Sulphate	17.76	28.3	46.6	11.1	—	—	1.81	26.6	26.0	23.7	25.1	25.4
Sodium Chloride	16.0	31.35	22.4	14.4	2.46	2.64	30.36	26.4	26.1	27.7	27.06	30.8
Sodium Nitrate	—	.4	—	—	1.7	1.23	.6	—	—	—	—	—
Silica	1.6	—	1.4	1.0	1.4	1.1	1.7	1.8	1.9	1.8	1.5	1.6
Organic Matter, etc.	1.0	.85	1.3	—	.23	.7	.45	1.11	1.2	.7	.67	.8
Total	65.0	122.0	106.0	54.0	35.0	33.6	91.0	81.5	80.0	79.6	80.0	83.5
Total Hardness	8.5	60	28	20	28	27	50	7.5	9.5	7	6.5	7.5
Free Ammonia	.1320	.0500	.0610	—	.0008	.0064	.0250	.0610	.0470	.0510	.0560	.0580
Albuminoid Ammonia	.0024	.0080	.0024	—	.0004	.0006	.0012	.0018	.0026	.0020	.0018	.0028
Oxygen Absorbed	.040	.084	.065	—	.005	.000	.015	.035	.035	.035	.030	.050

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

Number Source	CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS IN AND NEAR LONDON											
	265 Portland Place, W.	266 White- chapel, E.	267 Bow, E., 400 ft.	268 Millwall, E.	269 Lincolns- house, E.	270 Richmond	271 Richmond	272 Southall, 400 ft.	273 Southall, 600 ft.	274 Southall	275 Acton, W.	276 Wembley, 450 ft.
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	3.0	13.15	21.0	27.2	29.15	7.5	8.75	3.25	2.5	3.9	4.75	12.0
Calcium Sulphate	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	3.46	6.9	4.8	4.8	.28	4.0	3.65	1.5	1.75	3.81	3.10	9.8
Magnesium Sulphate	—	—	—	26.5	7.2	—	—	—	—	—	—	—
Magnesium Chloride	—	—	—	2.7	7.89	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	21.64	4.9	1.9	—	—	11.4	10.9	25.35	25.85	24.7	25.55	6.7
Sodium Sulphate	22.2	11.2	10.6	—	—	6.65	10.35	15.9	21.25	16.28	20.7	26.0
Sodium Chloride	28.0	10.0	6.4	295.2	14.4	8.1	12.4	15.0	18.8	14.03	19.1	18.9
Sodium Nitrate	—	.95	—	—	—	—	—	—	—	—	—	—
Silica	1.2	1.3	1.2	3.6 {	1.6	1.35 }	1.45	1.5	.35	1.1	1.3	1.3
Organic Matter, etc.	.5	.6	.1		1.98		—	—	—	.18	.8	.2
Total	80.0	49.0	46.0	360.0	62.5	39.0	47.5	62.5	70.5	64.0	75.3	74.9
Total Hardness	8	22	26	80	44	12.5	14	5.5	5	8.5	9	24
Free Ammonia	.0650	.0355	.0220	.1210	.0166	.1120	.0980	.0520	.1000	.0780	.0570	.1373
Albuminoid Ammonia	.0036	.0017	.0016	.0250	.0027	.0010	.0020	.0050	.0060	.0016	.0008	.0000
Oxygen Absorbed	.090	.030	.030	.304	.020	.008	.018	.030	.050	.025	.020	.000

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
CHALK UNDER LOWER LONDON TERTIARIES. DEEP WELLS NEAR LONDON, 277-280
CHALK AT OR NEAR OUTCROP. ESSEX WELLS, 281-288

Number Source	277 Greenford, 405 ft.	278 Perivale, 452 ft.	279 Osterley	280 Raynes Park	281 Littlebury	282 Newport	283 Saffron Walden	284 Limford	285 Heydon	286 Roydon	287 Quendon	288 Purfleet
Ferrous Carbonate	—	—	—	—	—	1.3	—	—	—	1.2	—	—
Calcium Carbonate	12.5	9.35	3.5	6.5	26.3	31.25	26.0	18.2	19.2	34.25	26.1	28.0
Calcium Sulphate	—	—	—	—	2.05	2.05	7.65	2.05	1.85	—	2.0	42.8
Calcium Chloride	—	—	—	—	—	—	5.65	—	2.35	—	.55	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	12.7	12.4	.35	7.2	—	—	—	—	—	—	—	—
Magnesium Sulphate	—	—	—	—	—	1.55	—	2.45	—	2.8	—	24.3
Magnesium Chloride	—	—	—	—	.8	1.2	.4	.6	—	—	.95	36.0
Magnesium Nitrate	—	—	—	—	—	—	3.1	—	1.2	—	—	—
Sodium Carbonate	2.12	5.3	17.05	6.9	—	—	—	—	—	—	—	—
Sodium Sulphate	32.26	22.5	14.2	6.5	—	—	—	—	—	—	—	—
Sodium Chloride	22.4	13.2	17.3	3.6	2.0	1.0	—	4.05	—	3.8	.9	513.2
Sodium Nitrate	—	—	—	—	2.95	.3	9.7	1.7	4.1	1.2	2.45	2.3
Silica	1.4	.7	1.6	1.3	3.4	3.35	.8	1.95	1.3	1.15	.3	2.4
Organic Matter, etc.	1.22	.55	.5	1.0		—	—	—	—	—	—	—
Total	84.6	64.0	54.5	33.0	37.5	42.0	53.3	31.0	30.0	44.4	33.3	649.0
Total Hardness	27	24.5	4	16	28	32	40	21.5	23	36	28	120
Free Ammonia	.0920	.0510	.0420	.0380	.000	.000	.000	.001	.000	.080	.000	.052
Albuminoid Ammonia	.0006	.0014	.0036	.0016	.002	.000	.006	.004	.004	.005	.001	.004
Oxygen Absorbed	.010	.030	.055	.025	.024	.024	.015	.012	.021	.120	—	.088

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK AT OR NEAR OUTCROP. ESSEX WELLS, 289-295. CHALK WATERS, HERTS., 296-300

Number Source	289 Grays	290 Grays	291 Aveley	292 Manning- tree	293 Dedham, 170 ft.	294 Langham	295 Newport, 250 ft.	296 Bishop's Stortford	297 Watford	298 Berk- hamstead	299 Ware	300 Otterspool
Ferrous Carbonate	—	15.8	18.5	—	16.0	19.4	—	—	—	—	—	—
Calcium Carbonate	27.2	4.95	12.5	30.2	—	—	29.0	26.5	25.3	20.25	16.3	24.65
Calcium Sulphate	12.2	.7	6.7	—	—	—	.2	4.0	3.4	.45	5.65	2.55
Calcium Chloride	3.4	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	4.6	—	—	—	—	—	3.44	—	5.8	2.4	—	—
Magnesium Carbonate	—	—	—	1.5	8.8	8.07	—	—	—	—	—	—
Magnesium Sulphate	—	—	—	12.54	1.48	9.28	1.25	—	—	—	2.4	—
Magnesium Chloride	9.9	1.5	2.8	15.86	—	—	—	2.0	1.2	—	—	1.15
Magnesium Nitrate	—	—	2.4	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	—	—	—	—	6.83	3.55	—	—	—	—	—	—
Sodium Chloride	62.7	4.95	—	86.9	18.3	50.2	3.5	.5	2.3	2.15	4.3	1.4
Sodium Nitrate	—	5.6	9.6	1.2	.97	.6	—	1.4	—	—	2.45	2.55
Silica	—	1.5	.5	{ 2.2	1.6	1.1	1.1	2.6	1.5	1.25	2.2	.7
Organic Matter, etc.	3.5	—	—	{ 1.1	1.02	1.8	.51	—	—	—	—	—
Total	123.5	35.0	53.0	151.5	55.0	94.0	39.0	37.0	39.5	26.5	33.3	33.0
Total Hardness	52	22	34	62.5	28	39	32	28	30	22	19	28
Free Ammonia	.040	.000	.000	.044	.0510	.0560	.0010	.002	.001	.000	.056	.004
Albuminoid Ammonia	.002	.001	.004	.002	.0012	.0016	.0008	.003	.006	.006	.014	.028
Oxygen Absorbed	.022	.025	.036	.035	.015	.030	.010	—	.027	.037	.213	.200

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS, HERTS.

Number Source	301 Eastbury	302 Sawridge- worth	303 Barnet	304 Bushey	305 Bushey	306 Bushey	307 Hertford	308 St. Albans	309 Watford	310 Mill End	311 Knebworth	312 Hunton Bridge
Ferrous Carbonate	—	Trace	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	26.0	24.5	24.55	26.6	25.3	18.3	24.5	26.5	28.5	25.5	27.0	24.0
Calcium Sulphate	3.75	—	4.05	10.55	5.25	9.2	1.0	2.7	1.36	2.0	3.23	1.28
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	2.05	1.9	—	—	—	—	—	—	1.11
Magnesium Carbonate	—	4.2	—	—	—	—	—	—	—	—	—	—
Magnesium Sulphate	—	—	.2	2.0	1.15	3.35	.51	.49	3.46	.98	.74	.78
Magnesium Chloride	—	—	2.4	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	2.51	—	—	—	—	—
Sodium Sulphate	2.3	6.65	—	—	—	—	—	—	1.15	—	—	—
Sodium Chloride	3.3	4.6	.65	4.3	3.65	3.8	2.8	2.8	5.78	2.3	3.13	.69
Sodium Nitrate	2.5	.4	3.5	1.85	1.9	2.6	2.55	2.47	4.39	2.6	2.06	.3
Silica	1.2	3.75	1.85	1.4	1.35	1.25	2.4	{ 1.0	1.4	1.2	.9	1.2
Organic Matter, etc.	.45	—	—	—	—	—	—	.24	.46	.42	.44	1.14
Total	38.0	44.1	37.2	48.75	40.5	38.5	36.0	36.2	46.5	35.0	37.5	30.5
Total Hardness	26	30	27	32	30	26	25	28.5	32.5	28	30	27
Free Ammonia	.003	.015	.001	.131	.005	.014	.0000	.0052	.0144	.0018	.0011	.0000
Albuminoid Ammonia	.002	.001	.008	.013	.006	.013	.0004	.0004	.0020	.0006	.0004	.0000
Oxygen Absorbed	.024	.011	.069	.146	.054	.135	.007	.010	.035	.010	.005	.005

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. HERTS., 313-317. SUFFOLK, 318-324

Number	313	314	315	316	317	318	319	320	321	322	323	324
Source	Rickmans- worth, 300 ft.	Batchworth	Welwyn	Potters Bar	Tyden- hanger	Haverhill	Brantham	Thorndon	Eye	Brandon	Stoke-by- Clare	Sudbury
Ferrous Carbonate	—	—	—	—	—	—	Trace	Trace	Trace	Trace	Trace	—
Calcium Carbonate	26.0	24.5	27.0	24.0	22.5	28.0	23.5	29.5	32.0	18.7	28.2	26.75
Calcium Sulphate	—	1.42	2.4	3.06	2.03	7.82	—	4.8	8.85	8.5	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	1.56	—	—	—	—	—	—	—	6.95	—	—
Magnesium Carbonate	—	—	—	—	—	—	6.45	—	—	—	—	—
Magnesium Sulphate	.52	—	—	.99	.59	10.87	7.2	—	.55	—	7.8	2.65
Magnesium Chloride	—	1.56	.98	—	—	—	1.75	3.95	1.2	2.0	2.5	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	.41	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	1.32	—	—	.96	—	2.68	—	—	—	—	—	5.45
Sodium Chloride	2.31	.4	.94	2.64	2.48	7.43	22.9	1.2	4.45	3.5	—	7.25
Sodium Nitrate	1.7	.08	2.2	—	2.05	—	.15	.3	.7	—	2.7	2.5
Silica	1.2	1.2	1.25	1.05	1.45	1.3	2.85	1.25	2.75	3.25	1.0	1.5
Organic Matter, etc.	.03	1.28	.73	.3	.9	.9		1.25	2.75	3.25	1.0	1.5
Total	33.5	32.0	35.5	33.0	32.0	59.0	64.8	41.0	50.5	42.9	55.3	46.1
Total Hardness	26.5	29	30	27	24.5	44	40	32	34.5	31	34	30
Free Ammonia	.0028	.0006	.0008	.0006	.0008	.0016	—	.020	.007	.002	.003	.002
Albuminoid Ammonia	.0008	.0004	.0000	.0000	.0004	.0006	—	.003	.004	.000	.001	.001
Oxygen Absorbed	.015	.010	.005	.005	.005	.010	—	.088	.130	.018	.033	.086

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. SUFFOLK, 325-331. NORFOLK, 332-336

Number	325	326	327	328	329	330	331	332	333	334	335	336
Source	Shotley	Wood- bridge	Wolver- stone	Felixstowe	Stow- market	Halesworth	Framling- ham	Wymondham	Cromer	Norwich	Wymondham, 300 ft.	Docking, 212 ft.
Ferrous Carbonate	—	29.7	22.5	—	31.7	28.3	—	—	—	—	Fe .12	—
Calcium Carbonate	25.3	—	—	21.25	—	—	28.0	25.65	19.3	14.3	29.5	18.5
Calcium Sulphate	35.4	23.45	—	—	6.95	19.0	2.04	.5	2.55	4.25	2.4	3.4
Calcium Chloride	12.2	5.4	—	—	—	—	—	—	—	—	—	1.6
Calcium Nitrate	—	—	—	—	—	—	—	—	—	5.8	—	—
Magnesium Carbonate	—	—	5.45	5.35	—	—	—	—	—	—	—	—
Magnesium Sulphate	—	—	13.0	7.0	.5	5.1	2.96	1.5	1.75	—	.5	—
Magnesium Chloride	65.2	6.7	.55	5.1	—	.4	—	—	—	1.0	—	1.1
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	3.25	—	3.26	1.35	.75	—	—	—
Sodium Sulphate	—	—	—	—	6.6	9.4	6.09	4.45	6.6	3.4	3.0	2.0
Sodium Chloride	390.2	4.55	44.9	28.15	—	.35	—	.4	.15	—	—	4.8
Sodium Nitrate	.5	15.5	.6	.6	—	—	—	—	—	—	—	—
Silica	—	—	—	—	1.0	.45	{ 1.5	{ 2.8	1.4	2.25	{ 1.0	.8
Organic Matter, etc. }	1.2	1.8	1.5	2.95	—	—	{ .65	—	—	—	{ 1.6	.1
Total	530.0	87.1	88.5	70.4	50.0	63.0	44.5	37.0	32.5	31.0	38.0	32.3
Total Hardness	100	58	48	34	30	50	32	28.5	22.5	22	28	23
Free Ammonia	.164	.000	.092	.001	.000	.012	.0240	.002	.002	.000	.0160	.0005
Albuminoid Ammonia	.001	.004	.006	.004	.000	.006	.0012	.005	.000	.002	.0028	.0000
Oxygen Absorbed	.039	.013	.036	.025	.018	.160	.040	.124	.016	.018	.040	.000

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. CAMBRIDGESHIRE, 337-345. BEDS., 346-348

Number	Source	337	338	339	340	341	342	343	344	345	346	347	348
			Sketch- worth	Ely	Pampisford	Linton	Cherry- hinton	Fulbourn	Fulbourn	Dullingham	Luton	Luton	Markyate
Ferrous Carbonate		—	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate		27.5	31.0	18.7	25.8	27.7	20.35	19.85	21.25	33.5	20.3	23.7	25.8
Calcium Sulphate		2.04	7.95	2.1	2.55	1.8	2.25	2.55	4.65	10.2	1.85	7.1	.35
Calcium Chloride		—	—	2.6	—	—	—	—	2.75	—	.95	—	2.0
Calcium Nitrate		—	—	2.8	—	—	—	—	—	—	4.1	12.9	1.6
Magnesium Carbonate		—	—	—	—	—	—	—	—	—	—	—	—
Magnesium Sulphate		2.96	2.47	—	2.5	2.5	.9	.8	—	3.9	—	—	—
Magnesium Chloride		—	—	.6	—	—	1.75	1.6	1.35	—	—	1.35	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate		—	.04	—	—	—	—	—	—	.45	—	—	—
Sodium Chloride		4.6	5.6	—	3.1	3.1	.55	.8	—	7.0	1.15	4.8	—
Sodium Nitrate		1.2	.35	—	2.6	2.0	3.95	3.95	7.1	—	—	—	—
Silica		2.1	1.6	} 3.2	2.05	1.5	2.45	1.95	1.9	1.95	1.65	2.15	.25
Organic Matter, etc.		—	.29		—	—	—	—	—	—	—	—	—
Total		40.4	49.3	30.0	38.6	38.6	32.5	31.5	39.0	57.0	30.0	52.0	30.0
Total Hardness		32	38.5	21	30	30	24	24	29	45	25	38.5	30
Free Ammonia		.0028	.0034	.000	.000	.000	.0006	.001	.001	.004	.000	.000	.000
Albuminoid Ammonia		.0004	.0002	.005	.000	.000	.0007	.004	.003	.002	.001	.000	.000
Oxygen Absorbed		.010	.010	.032	.015	.016	—	—	—	.025	.007	.007	.007

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. LINGS., 349-353. MIDDLESEX, 354-359

Number	Source	349	350	351	352	353	354	355	356	357	358	359
		Mablethorpe	Wilton	Killingholme	Grimsby, 64 ft.	Grimsby	Pinner	Hayes	West Drayton, 200 ft.	Uxbridge	Staines	Ickenham
		29.3	2.6	Fe. .84 28.75	19.0	20.25	27.8	3.5	14.25	18.75	7.5	22.25
Ferrous Carbonate		—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate		—	—	—	1.02	—	—	—	—	—	—	—
Calcium Sulphate		—	—	—	—	—	—	—	—	—	—	—
Calcium Chloride		—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		7.3	.7	3.15	—	1.05	2.9	2.45	4.15	3.52	1.54	.63
Magnesium Sulphate		—	—	10.4	1.0	1.0	4.8	—	—	—	—	2.07
Magnesium Chloride		6.2	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	27.6	—	—	—	—	—	3.5	1.15	1.4	—
Sodium Sulphate		48.1	4.0	4.92	.42	2.81	4.55	25.0	2.96	4.44	2.96	4.0
Sodium Chloride		—	3.95	46.2	2.64	11.06	8.25	30.5	2.47	3.3	18.6	3.47
Sodium Nitrate		—	—	1.78	2.55	.85	.3	14.7	—	—	—	—
Silica		—	—	{ 1.2	1.3	1.2	2.6	1.35	{ 1.2	1.1	1.6	1.25
Organic Matter, etc.		1.1	.65	{ 2.6	.57	.28	—	—	{ 1.07	.44	1.4	.33
Total		92.0	39.5	99.0	28.5	38.5	51.2	77.5	29.6	32.7	35.0	34.0
Total Hardness		31	4	42	21	22.5	32	7	21	23	9.5	25
Free Ammonia		.200	.060	.025	.0000	.0000	.004	.0760	.0420	.0150	.0345	.0026
Albuminoid Ammonia		.016	.002	.003	.0000	.0000	.003	.0025	.0008	.0004	.0008	.0004
Oxygen Absorbed		.072	.020	.055	.005	.000	.012	.026	.020	.005	.017	.010

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. SURREY

Number Source	360 Leatherhead	361 Woldingham	362 Chertsey	363 Sutton	364 Guildford	365 Guildford	366 Guildford	367 Clandon	368 Croydon	369 Horsley	370 Coulston
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	23.5	20.5	27.3	23.7	12.25	20.5	22.0	17.5	23.0	19.0	22.5
Calcium Sulphate	2.03	3.4	5.45	3.1	—	2.0	.35	2.38	1.7	1.28	2.54
Calcium Chloride	—	—	—	—	—	1.6	—	—	—	—	—
Calcium Nitrate	—	—	—	8.2	—	—	—	—	—	3.76	1.88
Magnesium Carbonate	—	—	—	—	7.35	—	—	—	—	—	—
Magnesium Sulphate	1.97	.5	2.7	—	—	—	.75	—	.3	—	—
Magnesium Chloride	—	.15	—	1.8	—	.4	1.0	.39	.94	.39	1.17
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	.6	—	2.3	—	—	—	—	—	—
Sodium Sulphate	3.3	2.54	3.95	—	4.7	—	—	—	—	—	—
Sodium Chloride	3.6	2.06	—	2.25	4.45	1.0	1.8	1.5	.83	1.67	1.04
Sodium Nitrate	—	—	—	2.9	—	3.6	2.5	1.95	1.33	—	—
Silica	1.1	.6	1.0	2.55	.45	1.1	.8	1.2	1.3	1.1	1.25
Organic Matter, etc.	.1	.25		—	—	—	—	.58	1.1	1.3	.62
Total	35.6	30.0	41.0	44.5	31.5	30.2	29.2	25.5	30.5	28.5	31.0
Total Hardness	28	23.5	32	34	21	24	24	19.5	26	22.5	27
Free Ammonia	.0040	.0020	.0010	.000	.001	.001	.002	.0004	.0008	.0008	.0000
Albuminoid Ammonia	.0034	.0000	.0040	.003	.003	.002	.035	.0006	.0000	.0004	.0006
Oxygen Absorbed	.015	.000	.040	.066	.022	.010	.021	.010	.000	.010	.015

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. SUSSEX

Number	Source	371	372	373	374	375	376	377	378	379	380	381
		Midhurst	Battle	Bognor	Newhaven	Eastbourne	Eastbourne	Slindon	Brighton	Brighton	Peasehaven	Chichester
						Nr.	Nr.					
Ferrous Carbonate		—	—	—	—	Trace	—	—	—	—	—	—
Calcium Carbonate		25.0	13.94	22.0	16.0	18.8	15.75	18.5	16.0	14.5	16.5	19.0
Calcium Sulphate		2.7	—	1.4	1.2	.55	1.9	3.05	2.4	3.2	2.98	.34
Calcium Chloride		—	—	.7	—	.9	2.65	—	.55	.55	—	—
Calcium Nitrate		—	—	—	—	2.4	1.85	—	2.15	4.45	1.52	—
Magnesium Carbonate		—	1.73	—	—	—	—	—	—	—	—	—
Magnesium Sulphate		1.5	—	—	.5	—	—	—	—	—	—	.74
Magnesium Chloride		—	—	.4	—	1.2	1.0	.39	.6	1.0	.39	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	1.08	—	—	—	—	—	—	—	—	—
Sodium Sulphate		—	3.7	—	—	—	—	—	—	—	—	2.03
Sodium Chloride		2.6	5.61	2.7	5.6	3.85	4.05	2.49	2.0	3.6	4.97	2.81
Sodium Nitrate		2.2	—	2.6	.4	—	—	1.45	—	—	.85	.48
Silica		1.6	1.3	.9	2.9	1.3	1.8	{ 1.1	{ 1.3	{ 1.2	{ .95	{ 1.1
Organic Matter, etc.		.7	.44	.3	—	—	—	.52	—	—	1.14	.5
Total		36.3	27.8	31.0	26.6	29.0	29.0	27.5	25.0	28.5	29.3	27.0
Total Hardness		28.5	15	24	17	21	19	20.5	19	24	20	20
Free Ammonia		.0008	.0106	.003	.004	.001	.000	.0000	.000	.000	.0000	.0000
Albuminoid Ammonia		.0006	.0024	.002	.009	.002	.001	.0000	.001	.006	.0004	.0000
Oxygen Absorbed		.020	.020	.011	.098	.025	.015	.005	.006	.055	.015	.000

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. BUCKS.

Number Source	382 Slough	383 Little Kimbles	384 Burnham	385 Chesham	386 Boveney	387 Freith, nr. Marlow	388 Datchet	389 High Wycombe	390 Amersham	391 Stone	392 Monks Risborough
Ferrous Carbonate	—	—	—	—	.25	—	—	—	—	—	—
Calcium Carbonate	16.5	23.2	24.6	23.75	18.5	27.5	27.5	22.5	21.6	21.5	18.75
Calcium Sulphate	—	—	3.55	—	—	—	.68	2.0	3.0	15.5	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	4.75	—
Magnesium Carbonate	3.6	2.0	—	.5	12.1	.42	—	—	—	—	—
Magnesium Sulphate	—	3.5	—	—	—	.15	4.09	.25	.23	—	2.6
Magnesium Chloride	—	—	—	—	—	—	—	—	.88	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	.84	—
Sodium Carbonate	3.7	—	—	—	—	—	—	—	—	—	1.77
Sodium Sulphate	7.55	—	1.2	.6	22.2	.41	5.98	—	—	—	3.92
Sodium Chloride	5.6	2.3	3.3	2.0	18.8	1.98	4.73	2.47	1.24	5.2	2.15
Sodium Nitrate	1.25	.2	4.5	2.4	.25	1.95	1.91	3.0	2.2	1.5	—
Silica	—	—	—	—	—	1.4	1.5	1.5	1.1	.8	2.2
Organic Matter, etc.	1.45	1.9	2.2	1.25	1.15	.19	.61	.28	.36	.21	.31
Total	39.4	32.1	39.4	30.5	73.2	34.0	47.0	32.0	30.6	50.3	31.7
Total Hardness	22	24	27	24	34	28	31.5	24	26	36	22
Free Ammonia	.023	.014	.0010	.0050	.080	.0036	.0010	.0016	.0022	.0044	.0192
Albuminoid Ammonia	.005	.002	.0045	.0025	.002	.0012	.0030	.0008	.0006	.0034	.0000
Oxygen Absorbed	.023	—	.010	.014	.032	.020	.012	.015	.015	.030	.010

* Possibly from Upper Greensand.

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. BERKS.

Number Source	393 Pangbourne	394 Reading	395 Windsor	396 Aldermaston	397 Faringdon	398 Southcoate	399 Sonning. 100 ft.	400 Wantage	401 Bradfield. 160 ft.	402 Woodley. 175 ft.	403 Wokingham. 408 ft.
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	24.5	23.65	21.8	21.75	28.0	20.5	25.5	22.5	22.0	11.0	6.0
Calcium Sulphate	1.7	.85	6.35	—	5.78	2.72	9.06	3.74	2.38	—	—
Calcium Chloride	—	.8	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	1.39	—	—	—	—
Magnesium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Sulphate	—	3.5	—	—	1.73	.49	—	1.33	1.48	8.6	4.5
Magnesium Chloride	.39	—	2.35	—	—	—	2.54	.9	—	—	—
Magnesium Nitrate	—	.8	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	.35	13.4
Sodium Sulphate	—	—	—	2.4	1.78	1.02	—	—	.8	8.6	11.8
Sodium Chloride	2.0	.65	1.05	2.8	2.48	2.48	1.5	.54	2.15	13.4	62.7
Sodium Nitrate	2.47	—	3.5	.2	—	—	5.28	1.95	1.95	—	.73
Silica	.94	} 1.55	1.45	1.65	1.2	1.1	1.3	1.05	1.4	1.7	1.4
Organic Matter, etc.	.3		—	—	1.03	.69	.43	.49	.84	1.35	1.47
Total	32.3	34.5	36.5	32.5	42.0	29.0	47.0	32.5	33.0	45.0	102.0
Total Hardness	28	29	30.5	25	34	22.5	36	28	25	22	11.5
Free Ammonia	.0022	.001	.000	.010	.0024	.0032	.0000	.0018	.0000	.0520	.0130
Albuminoid Ammonia	.0008	.001	.004	.005	.0030	.0008	.0000	.0004	.0000	.0040	.0032
Oxygen Absorbed	.010	.006	.023	.070	.040	.015	.005	.015	.005	.010	.040

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. BERKS., 404-411. OXON., 412-413. RUTLAND, 414

Number	404	405	406	407	408	409	410	411	412	413	414
Source	Toutley. 245 ft.	Toutley. 360 ft.	Mortimer. 253 ft.	Dedworth Windor. 450 ft.	Grazeley	Clewer	Arboret. 340 ft.	Beenhams Heath	Goring. 70 ft.	Henley. 230 ft.	Ashwall
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	9.0	8.5	10.5	8.75	9.75	8.75	12.5	16.75	22.5	26.0	21.7
Calcium Sulphate	—	—	—	—	—	—	—	—	.68	2.04	1.85
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	2.65
Calcium Nitrate	—	—	—	—	—	—	—	—	—	2.46	—
Magnesium Carbonate	7.9	8.6	3.8	5.88	10.73	7.61	7.6	6.11	—	—	—
Magnesium Sulphate	—	—	—	—	—	—	—	5.14	1.24	—	—
Magnesium Chloride	—	—	—	—	—	—	—	—	—	1.56	.65
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	1.05
Sodium Carbonate	5.0	4.6	7.97	8.27	.57	7.15	3.7	—	—	—	—
Sodium Sulphate	13.9	18.1	11.25	28.42	3.55	24.57	6.2	9.32	.54	—	—
Sodium Chloride	19.1	22.2	14.52	42.24	12.87	38.28	8.6	19.47	2.15	.56	—
Sodium Nitrate	—	—	—	—	—	—	—	—	3.02	—	3.65
Silica	1.2	1.0	1.3	1.3	1.4	1.1	1.4	1.25	1.2	1.4	1.45
Organic Matter, etc.	.9	1.0	.66	1.64	1.13	1.54	1.0	1.46	.67	.48	—
Total	57.0	64.0	50.0	96.5	40.0	89.0	41.0	59.5	32.0	34.5	33.0
Total Hardness	18	18	15.5	16	23	18	22	29	24.0	31	24
Free Ammonia	.1040	.0960	.0720	.1040	.0168	.1200	.0880	.0880	.0044	.0012	.001
Albuminoid Ammonia	.0024	.0020	.0004	.0008	.0000	.0008	.0000	.0000	.0000	.0004	.002
Oxygen Absorbed	.030	.025	.010	.010	.000	.010	.005	.005	.005	.005	.024

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. DORSET, 415-418. HAMPSHIRE, 419-425

Number	415	416	417	418	419	420	421	422	423	424	425
Source	Svanage	Corfe Mullen	Nr. Poole	Wimborne	Foxbury	Foxbury	Foxbury Fissure A	Foxbury, Fissure B	Forton	Bury Cross	Clapperton
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	18.3	21.25	18.5	23.25	17.15	19.5	15.5	25.0	5.2	13.5	17.75
Calcium Sulphate	—	2.55	1.0	—	—	—	—	6.45	19.7	—	1.65
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	—	1.9	5.3	4.35	8.75	—	—	—	3.0
Magnesium Sulphate	.5	.85	1.7	3.5	1.0	9.5	—	9.55	13.0	—	—
Magnesium Chloride	—	1.6	—	—	—	2.15	—	9.1	2.75	—	1.0
Magnesium Nitrate	—	—	—	—	—	—	—	—	.65	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	.35	—	—	—	9.3	—	8.3	—	—	11.1	—
Sodium Chloride	5.65	3.0	3.8	4.0	59.05	67.3	37.1	127.0	69.35	11.7	1.4
Sodium Nitrate	1.5	.6	1.4	.2	.15	.4	.8	.4	—	.8	—
Silica	1.5	.65	.6	1.15	.55	1.6	.35	.5	2.35	.6	2.7
Organic Matter, etc. }											
Total	27.8	30.5	27.0	34.0	92.5	104.8	70.8	178.0	113.0	43.5	27.5
Total Hardness	18	26.5	19	25	25	37	24	50	33	16	23
Free Ammonia	.002	.000	.000	.005	.070	.066	—	—	.000	.118	.000
Albuminoid Ammonia	.011	.001	.003	.001	.003	.001	—	—	.000	.005	.003
Oxygen Absorbed	.074	.008	.000	.022	.042	.017	—	—	.003	.021	.126

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. HAMPSHIRE

Number	426	427	428	429	430	431	432	433	434	435	436
Source	Nr. Portsmouth	Portsmouth	Otterbourne	Owlesbury	Andover	Shallow Adit.	Nr. Southampton Deep Adit.	Winchester	Soberton	Woodston	Aldershot
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	Trace	—
Calcium Carbonate	20.8	18.75	22.0	18.3	21.35	22.0	24.7	19.5	25.0	21.9	23.6
Calcium Sulphate	.7	—	.7	.55	1.15	.85	.85	.9	—	6.2	3.6
Calcium Chloride	.85	—	1.4	—	—	1.25	1.0	—	—	4.15	—
Calcium Nitrate	2.55	—	2.55	2.9	4.9	—	—	5.9	—	—	—
Magnesium Carbonate	—	1.0	—	—	—	—	—	—	1.3	—	—
Magnesium Sulphate	—	16.0	—	—	—	—	—	—	1.0	—	.95
Magnesium Chloride	.8	—	.6	.5	.4	.4	.4	1.2	—	11.5	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	—	5.05	—	—	—	—	—	—	.7	—	—
Sodium Chloride	.75	81.35	.25	.4	2.15	.9	1.3	1.3	3.1	105.3	3.6
Sodium Nitrate	—	.25	—	—	—	1.5	1.5	—	—	—	2.15
Silica	1.05	3.2	3.0	3.35	2.05	1.1	1.1	.7	1.5	8.45	3.1
Organic Matter, etc.	—	—	—	—	—	—	—	—	—	—	—
Total	27.5	125.6	30.5	26.0	32.0	29.0	31.2	29.5	32.6	158.0	37.0
Total Hardness	26	24	26	22	22.5	25	26	26	26.5	50	26
Free Ammonia	.000	.088	.000	.000	.000	.001	.000	.001	.000	.160	.001
Albuminoid Ammonia	.001	.000	.003	.001	.003	.001	.000	.002	.001	.011	.001
Oxygen Absorbed	.063	.096	.008	.029	.022	.011	.009	.014	.011	.040	.006

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. HAMPSHIRE

Number	437	438	439	440	441	442	443	444	445	446	447
Source	Otterbourne	Fimsbury	Havant	Nr. Romsey	Romsey	Exbury	Exbury, 860 ft.	Eastleigh, 650 ft.	Itchel	Alresford	Greywell
Ferrous Carbonate	—	—	—	Fe .24	—	—	—	—	—	—	—
Calcium Carbonate	22.5	25.0	19.5	15.05	11.55	9.75	11.0	9.6	24.5	21.5	21.5
Calcium Sulphate	1.7	—	.7	—	—	3.7	—	—	1.7	1.7	2.41
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	3.27
Magnesium Carbonate	—	1.0	—	2.1	5.2	—	.84	7.95	—	—	—
Magnesium Sulphate	.38	—	.88	2.96	—	—	4.24	.98	1.24	.5	—
Magnesium Chloride	—	—	—	—	—	1.55	—	—	—	.4	.78
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	.5	—	—	4.6	—	—	—	—	—	—
Sodium Sulphate	—	1.48	—	—	4.0	—	2.4	10.3	—	—	—
Sodium Chloride	2.48	2.8	3.13	2.64	7.4	4.37	4.12	39.8	2.15	1.48	1.19
Sodium Nitrate	1.95	1.7	1.87	—	—	—	—	—	2.07	1.7	—
Silica	1.5	1.0	1.1	1.1	1.0	1.6	1.0	.8	1.1	1.2	1.1
Organic Matter, etc.	.49	.52	.52	.73	1.85	.53	1.0	1.3	.24	1.02	.75
Total	31.0	34.0	27.7	27.0	35.6	21.5	24.6	70.8	33.0	29.5	31.0
Total Hardness	24.5	26	22	20.5	18.5	14	15.5	20	27	24	26
Free Ammonia	.0004	.0016	.0018	.0086	.0170	.0048	.0440	.1216	.0002	.0016	.0010
Aluminoid Ammonia	.0008	.0020	.0012	.0011	.0006	.0011	.0028	.0020	.0000	.0008	.0004
Oxygen Absorbed	.015	.030	.015	.020	.010	.040	.040	.065	.010	.015	.005

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
CHALK WATERS. ISLE OF WIGHT, 448-453. KENT, 454-459

Number	448	449*	450	451	452	453	454	455	456	457	458	459
Source	Nr. Tot- land Bay	Broadfield	Shalcombe	Freshwater	Ryde. 160 ft.	Newport	Dartford	Northfleet, Boring 1	Northfleet, Boring 2	Northfleet	Dover	Dover
Ferrous Carbonate	—	—	17.9	16.8	18.5	17.5	27.15	Trace	Trace	27.25	20.5	19.0
Calcium Carbonate	20.0	14.75	1.3	4.1	2.38	2.83	1.9	30.65	28.8	—	20.5	1.85
Calcium Sulphate	5.1	—	—	—	—	—	3.0	22.4	21.4	—	1.15	1.7
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	1.4	—
Calcium Nitrate	—	—	—	—	—	1.11	—	—	—	—	2.65	4.9
Magnesium Carbonate	—	3.7	—	—	—	—	—	—	—	2.45	—	—
Magnesium Sulphate	2.5	—	—	1.9	1.48	—	—	5.4	2.5	1.0	—	—
Magnesium Chloride	—	—	—	6.25	—	.39	.95	3.95	—	—	.8	1.2
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	1.4	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	—	5.55	—	—	1.98	—	—	—	—	—	—	—
Sodium Chloride	15.2	3.3	6.3	26.95	5.45	4.47	—	59.8	28.05	4.1	1.5	5.8
Sodium Nitrate	.9	—	2.0	1.4	.48	.92	7.0	6.95	5.05	.75	—	—
Silica	.9	.4	—	—	1.3	.75	1.5	1.85	1.2	1.95	2.5	2.05
Organic Matter, etc.	—	—	.1	—	.43	.53	—	—	—	—	—	—
Total	44.6	29.1	27.6	57.4	32.0	28.5	41.5	131.0	87.0	37.5	30.5	35.5
Total Hardness	25	18	18	28	21.5	20.5	31	56	43	27	26	22
Free Ammonia	.003	.086	—	—	.0000	.0004	.004	.018	.012	—	.000	.000
Albuminoid Ammonia	.005	.002	—	—	.0000	.0006	.005	.007	.005	—	.001	.001
Oxygen Absorbed	.025	.000	—	—	.000	.015	.035	.086	.052	—	.032	.029

* Probably from Barton clay.

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. KENT

Number Source	460 Rochester	461 Chatham	462 Ramsgate	463 Bexley	464 Swans- combe	465 Greenhithe	466 Gravesend	467 Gravesend	468 St. Mary Cray	469 Faversham	470 Deptford
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	25.0	25.3	24.7	20.82	27.5	25.0	25.0	25.5	22.5	26.2	27.3
Calcium Sulphate	2.4	—	4.7	.9	4.75	—	2.55	2.72	1.15	.7	19.15
Calcium Chloride	—	—	1.8	—	4.55	—	3.45	—	.8	2.2	1.25
Calcium Nitrate	—	—	5.55	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	1.1	—	—	—	.85	—	—	—	—	—
Magnesium Sulphate	1.9	—	—	—	—	—	—	.6	—	—	—
Magnesium Chloride	—	—	4.95	1.2	2.75	—	.55	1.87	.8	1.1	12.9
Magnesium Nitrate	—	—	—	—	—	—	2.75	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	—	.8	—	—	—	1.9	—	—	—	—	—
Sodium Chloride	6.3	3.8	20.7	2.05	—	10.9	—	8.43	.5	—	22.1
Sodium Nitrate	3.0	2.1	—	7.2	9.55	2.0	4.75	3.97	3.0	1.8	—
					KNO ₃	1.55					
Silica	2.05	1.3	1.1	1.8	2.85	.35	.95	1.6	.25	1.0	4.3
Organic Matter, etc.											
Total	35.5	34.4	63.5	34.0	53.5	41.0	40.0	44.7	29.0	33.0	87.0
Total Hardness	22	26	38	21.5	38	25	34	30	26	29	56
Free Ammonia	.000	.001	.000	.000	.002	.006	.006	.002	.001	—	.050
Albuminoid Ammonia	.001	—	.002	.001	.022	.014	.003	.001	.002	—	.005
Oxygen Absorbed	.029	.024	.078	.021	.114	.068	.018	.000	.020	—	—

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS. KENT, 471-479. YORKS., 480-482													
Number Source	471 Charlton	472 Herne Bay	473 Ford	474 Canterbury	475 Westgate	476 Westgate	477 Wingham	478 Folkestone	479 Dartford	480 Hornsea	481 Hornsea	482 Holly	
Ferrous Carbonate	3.0	—	—	—	—	—	—	—	—	Trace	—	.7	
Calcium Carbonate	26.6	3.35	24.0	12.5	21.6	24.0	21.5	22.5	24.0	19.25	23.25	26.65	
Calcium Sulphate	3.0	—	—	—	2.55	2.83	3.82	2.38	7.48	6.25	—	18.2	
Calcium Chloride	—	—	—	—	—	—	6.32	—	—	—	—	—	
Calcium Nitrate	—	—	—	—	3.9	2.75	—	—	4.51	—	—	—	
Magnesium Carbonate	—	3.5	2.53	12.6	—	—	—	—	—	—	1.35	—	
Magnesium Sulphate	4.9	—	5.78	2.47	—	—	—	.59	—	3.6	6.8	31.6	
Magnesium Chloride	—	—	—	—	1.56	1.96	.47	—	.99	1.6	—	—	
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—	
Sodium Carbonate	—	23.0	—	—	—	—	—	—	—	—	—	—	
Sodium Sulphate	.9	41.75	3.24	25.5	—	—	—	—	—	—	.5	38.85	
Sodium Chloride	10.6	36.3	25.74	11.7	5.02	6.5	35.66	3.8	2.41	45.85	9.25	43.55	
		KCl 5.65											
Sodium Nitrate	—	—	—	.36	1.06	2.25	2.92	2.2	.67	—	.15	—	
Silica	—	—	{ 1.5	1.0	1.1	1.25	1.3	.9	1.1	—	—	—	
Organic Matter, etc.	1.0	.45	{ 1.21	.37	.81	1.95	1.01	.13	1.34	1.45	.2	3.45	
Total	50.0	114.0	64.0	66.5	37.6	43.5	73.0	32.5	42.5	78.0	41.5	163.0	
Total Hardness	35	8	32	30	28	30	30	24.5	.33	28	30	62	
Free Ammonia	.032	.072	.0136	.0820	.0008	.0260	.0022	.0000	.0000	.116	.076	.096	
Albuminoid Ammonia	.010	.004	.0004	.0012	.0000	.0008	.0008	.0004	.0000	.008	.070	.008	
Oxygen Absorbed	.175	.105	.010	.015	.005	.015	.010	.005	.005	—	—	.096	

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CHALK WATERS.		WILTS., 483-486.		UPPER GREENSAND, 487-488.		LOWER GREENSAND.		SURREY, 489-494					
Number	Source	483	484	485	486	487	488	489	490	491	492	493	494
		War-	Shrewton	Marl-	Salisbury.	Plumpton,	East	Shere	Ottershaw	Farnham	Farnham	Farnham	Croydon
		minster		borough	180 ft.	Sussex	Harting, Sussex		Park				
Ferrous Carbonate		—	—	—	—	1.2	—	—	.25	.3	Fe .35	—	—
Calcium Carbonate		19.0	19.0	21.2	25.5	26.5	28.2	9.0	12.0	27.0	6.75	9.5	10.75
Calcium Sulphate		1.1	.4	.35	2.04	—	—	1.65	8.15	—	—	—	—
Calcium Chloride		1.6	.95	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		2.9	1.7	2.35	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		—	—	—	—	1.25	2.0	—	—	.55	1.55	3.46	1.9
Magnesium Sulphate		—	—	—	.49	1.5	—	—	2.4	1.0	—	—	—
Magnesium Chloride		—	—	.4	—	—	—	1.0	1.0	—	—	—	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	—	—	—	—	.35	—	—	—	3.25	4.14	—
Sodium Sulphate		—	—	—	.84	3.0	2.35	—	—	—	3.55	2.65	3.26
Sodium Chloride		—	1.15	1.2	2.15	4.45	3.95	.75	58.85	2.65	3.4	6.1	2.15
Sodium Nitrate		—	—	—	1.95	—	1.1	1.25	.25	—	—	—	—
Silica		1.9	1.3	1.5	1.53	.5	1.05	1.55	1.9	1.1	{ .9	1.0	1.2
Organic Matter, etc.											{ 1.6	.75	1.24
Total		26.5	24.5	27.0	34.5	38.4	39.0	15.2	84.8	32.6	26.3	27.6	20.5
Total Hardness		27	19	23	27	30	26	11	22	29	9	14	13
Free Ammonia		.002	.008	.000	.0000	—	.016	—	.018	.007	.0270	.0410	.0124
Albuminoid Ammonia		.002	.005	.001	.0008	—	.006	—	.001	.004	.0072	.0014	.0000
Oxygen Absorbed		.075	.018	.014	.025	—	.047	—	.032	.022	.460	.020	.000

RESULTS OF ANALYSIS

* RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LOWER GREENSAND. SURREY, 495-504. SUSSEX, 505

Number	Source	495	496	497	498	499	500	501	502	503	504	505
		Reigate	Virginia Water. 1,426 ft.	Virginia Water. 800 ft.	Clandon	Godalming	Godalming	St. Heller. 1,300 ft.	Hindhead	Tilford	Westwood	Rogate
Ferrous Carbonate		—	—	—	—	—	—	—	—	—	—	Trace
Calcium Carbonate		7.5	11.0	4.25	5.5	13.5	17.5	7.75	4.0	10.5	11.75	.85
Calcium Sulphate		4.4	12.2	—	4.89	5.95	2.72	—	2.55	—	—	2.2
Calcium Chloride		—	—	—	26.2	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	2.83	—	—	.41	—	—	—
Magnesium Carbonate		—	—	1.9	—	—	—	1.04	—	.42	.21	—
Magnesium Sulphate		—	—	—	—	—	.49	—	—	—	.3	—
Magnesium Chloride		1.95	4.7	—	3.91	.39	—	—	.39	—	—	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	—	12.74	—	—	—	2.67	—	—	—	—
Sodium Sulphate		—	—	4.14	—	—	1.91	3.11	—	1.63	1.72	—
Sodium Chloride		.9	53.6	20.79	39.52	3.81	2.64	1.65	2.32	1.82	2.64	2.5
Sodium Nitrate		5.6	—	—	—	—	—	—	1.76	—	—	1.0
Silica		.65	{ 1.5	1.2	.95	1.15	1.25	1.2	1.15	1.05	.85	.85
Organic Matter, etc.			{ 1.0	.98	1.53	.37	.49	.58	.12	.88	.53	
Total		21.0	84.0	46.0	82.5	28.0	27.0	18.0	12.7	16.3	18.0	7.4
Total Hardness		13	25	6.5	37	20	19.5	9.5	6.5	11.0	12	2.5
Free Ammonia		.000	.0204	.0860	.0080	.0026	.0048	.0320	.0000	.0000	.0004	.000
Albuminoid Ammonia		.002	.0023	.0000	.0000	.0006	.0000	.0000	.0000	.0000	.0002	.000
Oxygen Absorbed		.008	.020	.005	.005	.010	.005	.015	.005	.000	.005	.016

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LOWER GREENSAND. KENT, 506-514. BERKS., 515-516

Number Source	506 Rochester	507 Saltwood	508 Sevenoaks	509 Dunton Green	510 Kemsing	511 Deal	512 Deal, 850 ft.	513 Halling	514 Ashford	515 Hungerford	516 Stevenon, 180 ft.
Ferrous Carbonate	.1	—	—	—	—	—	—	—	Fe .26	—	—
Calcium Carbonate	6.0	7.5	16.8	18.2	14.1	.88	2.5	15.0	22.5	5.0	2.75
Calcium Sulphate	—	5.25	2.7	2.8	2.95	—	—	—	3.4	—	—
Calcium Chloride	—	1.1	1.95	.4	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	2.2	—	—	—	—	.1	1.24	.85	—	Trace	.35
Magnesium Sulphate	—	—	—	—	.2	—	—	1.0	1.24	—	—
Magnesium Chloride	—	1.2	.8	1.75	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	19.5	—	—	—	—	47.2	56.85	—	—	19.1	34.87
Sodium Sulphate	4.7	—	—	—	—	15.8	1.48	—	.16	4.4	25.16
Sodium Chloride	92.9	1.75	.7	.4	3.65	8.58	72.6	3.3	2.97	1.65	123.75
Sodium Nitrate	—	6.4	2.3	.3	—	—	—	.35	—	—	—
Silica	2.6	1.9	.25	1.45	.9	{ 1.0	1.5	{ 1.2	{ 1.1	1.2	1.1
Organic Matter, etc.	—	—	—	—	—	.84	.8	—	.63	.67	2.02
Total	128.0	25.1	25.5	25.3	21.8	74.4	137.0	21.7	32.0	32.0	190.0
Total Hardness	11	10.5	17.5	20	17	1	4	15	26	5	3
Free Ammonia	.072	.032	.000	.000	.002	.0052	.0470	.000	.0072	.0230	.0850
Aluminoid Ammonia	.009	.007	.002	.000	.002	.0110	.0084	.001	.0038	.0004	.0012
Oxygen Absorbed	—	.080	.010	.008	—	.125	.225	.021	.070	.010	.055

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LOWER GREENSAND. BEDS., 517-522. BUCKS., 523-527

Number Source	517 Linslade	518 Leighton Buzzard	519 Leighton Buzzard	520 Dunstable, 423 ft.	521 Woburn, 80 ft.	522 Battlesden, 230 ft.	523 Nr. Slough	524 Slough	525 Slough, 1,045 ft.	526 Cheddington	527 Wing
			Fe .8			2.3	.4				
Ferrous Carbonate	Trace	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	26.3	13.5	6.25	15.5	2.0	14.0	3.2	9.2	7.5	18.65	38.15
Calcium Sulphate	10.9	5.8	—	1.02	2.83	6.46	—	—	—	—	4.6
Calcium Chloride	—	—	—	—	2.14	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	1.05	—	—	—	1.0	1.8	1.4	1.6	—
Magnesium Sulphate	3.75	2.0	.75	1.48	—	1.98	—	—	—	—	14.85
Magnesium Chloride	1.5	.54	—	—	.94	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	7.1	7.6	—	3.25	—
Sodium Sulphate	—	—	2.07	4.29	—	5.12	13.1	5.1	9.35	2.65	6.35
Sodium Chloride	—	4.0	.82	2.81	.38	2.64	62.0	7.0	5.77	4.3	7.6
Sodium Nitrate	—	4.1	.68	—	2.88	—	—	—	6.75	—	—
Silica	—	1.6	.5	1.2	.8	1.2	1.4	1.0	1.1	1.05	.45
Organic Matter, etc.	1.85	{ .46	{ .58	.2	.53	.3	{	{ 1.6	{ 1.63	{	
Total	44.3	32.0	12.7	26.5	12.5	34.0	88.2	33.3	33.5	31.5	72.0
Total Hardness	35	20	9	17.5	7	21	4	10	8	21	55
Free Ammonia	.006	.0160	.0032	.0040	.0000	.0072	—	.0016	.0180	.048	.002
Albuminoid Ammonia	.007	.0028	.0017	.0008	.0000	.0008	—	.0052	.0002	.001	.016
Oxygen Absorbed	.050	.040	.215	.015	.000	.085	.016	.050	.005	.009	.448

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LOWER GREENSAND

Number	Source	528 Hammonds- Worth, Middlesex, 1,190 ft.	529 Cambridge, 180 ft.	530 Cambridge, 200 ft.	531 Nr. Cambridge	532 East Hadley, Cambs., 250 ft.	533 Wolterton, Norfolk, 89 ft.	534 Petersfield, Hants.	535 Liss, Hants.	536 Aldershot, Hants.	537 Godshill, I.O.W.	538 Wanborough, Wilts.
Ferrous Carbonate		—	—	—	—	—	1.2	.4	—	—	—	—
Calcium Carbonate		18.5	18.75	9.5	25.0	27.5	24.0	14.0	.6	2.0	5.0	21.0
Calcium Sulphate		22.4	—	—	5.1	18.7	—	—	.37	—	1.7	2.4
Calcium Chloride		—	—	—	—	—	—	—	—	—	—	2.65
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		—	3.45	4.8	—	—	.42	2.4	—	.87	—	—
Magnesium Sulphate		20.3	—	—	17.8	13.54	1.63	—	—	—	—	—
Magnesium Chloride		4.3	—	—	—	4.93	—	—	1.24	—	1.9	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	2.3	.7
Sodium Carbonate		—	1.24	1.95	—	—	—	—	—	—	—	—
Sodium Sulphate		—	15.6	25.9	7.7	—	3.7	4.45	.22	8.99	—	—
Sodium Chloride		720.7	4.8	8.25	10.5	9.29	2.64	2.65	1.98	3.26	1.15	—
Sodium Nitrate		—	.55	—	—	—	—	—	1.95	10.23	1.37	8.05
Silica		1.2	1.0	1.15	1.8	1.35	.9	{		.9	1.0	—
Organic Matter, etc.		{ 42.6	.61	.45	.6	1.69	.21	.5	.5	1.25	1.58	—
Total		830.0	46.0	52.0	68.5	77.0	34.5	24.4	7.0	27.5	16.0	34.8
Total Hardness		56	23	16	45	58	26	17	2	3	10	26
Free Ammonia		.2250	.0310	.0028	.0960	.0420	.0052	.000	.0020	.0320	.0036	—
Albuminoid Ammonia		.0035	.0052	.0016	.0012	.0004	.0016	.001	.0016	.0000	.0006	—
Oxygen Absorbed		.370	.045	.025	.065	.015	.025	.010	.020	.005	.005	—

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

WEALD CLAY. SURREY, 539-544. HASTINGS BEDS. KENT, 545-549

Number Source	539 Horley	540 Horley, 120 ft.	541 Horley, 300 ft.	542 Dunsfold	543 Oakley, 102 ft.	544 Oakley, 85 ft.	545 South- borough	546 Tunbridge Wells	547 Cranbrook	548 East Ashford	549 Stye Place, Hadlow
Ferrous Carbonate	—	—	—	Trace	—	—	—	.3	Trace	Fe .9	—
Calcium Carbonate	.5	1.87	.87	10.0	2.0	1.0	5.0	2.25	7.25	5.0	.75
Calcium Sulphate	—	—	—	—	—	—	—	—	1.35	5.95	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	.07	.18	.11	—	.85	.42	2.1	1.05	—	—	.13
Magnesium Sulphate	—	—	—	—	—	—	—	—	—	1.5	—
Magnesium Chloride	—	—	—	—	—	—	—	—	.75	.39	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	47.15	45.6	79.65	36.0	48.3	31.3	2.2	11.95	—	—	71.26
Sodium Sulphate	Trace	44.4	2.37	3.7	56.2	111.0	2.9	5.2	—	—	Trace
Sodium Chloride	3.63	71.77	27.2	24.3	115.5	19.5	5.6	4.95	4.7	4.46	25.4
Sodium Nitrate	—	—	—	1.1	—	—	2.05	—	—	—	—
Silica	1.6	1.5	1.2	.9	.8	.8	} 1.65	.6	1.65	1.3	1.8
Organic Matter, etc.	1.05	2.68	.6	—	2.35	1.98		—	—	2.0	.66
Total	54.0	168.0	112.0	76.0	226.0	166.0	21.5	26.3	19.5	20.6	100.0
Total Hardness	0.5	2	1	10	3	1.5	8.5	3	11	11	0.7
Free Ammonia	.0320	.0810	.0810	.0160	.1100	.0192	.002	.048	.002	.0042	.0160
Albuminoid Ammonia	.0036	.0024	.0024	.0280	.0024	.0016	.003	.004	.002	.0020	.0060
Oxygen Absorbed	.0135	.045	.040	.210	.045	.045	.009	.028	.007	.019	.060

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

HASTINGS BEDS. SUSSEX

Number	Source	550	551	552	553	554	555	556	557	558	559	560
		Horsted	Mid Sussex	Mid Sussex	Horsham	Nr. Wadhurst	Nr. Boxhill	Nr. Boxhill	Nr. Boxhill	Nr. Boxhill	Hailsham.	Hailsham.
		Keynes	1	2							167 ft.	87 ft.
Ferrous Carbonate		.5	Trace	Trace	Trace	Trace	←	←	←	←	←	←
Calcium Carbonate		22.15	2.0	1.5	2.05	16.25	6.0	3.63	4.15	3.55	2.9	4.4
Calcium Sulphate		—	—	—	—	—	3.83	—	—	—	—	—
Calcium Chloride		—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		—	—	—	.75	—	—	1.4	1.73	1.38	.21	1.36
Magnesium Sulphate	5.05	—	—	—	—	1.45	2.57	—	—	—	—	—
Magnesium Chloride	—	—	—	—	—	1.75	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	42.8	41.15	10.16	—	—	5.52	2.98	3.7	3.56	—
Sodium Sulphate	—	—	6.2	29.6	2.52	2.65	1.26	4.76	5.93	6.66	6.36	3.18
Sodium Chloride	4.35	—	47.8	32.6	3.14	4.8	8.6	7.26	6.27	4.29	7.3	5.94
Sodium Nitrate	.5	—	—	—	—	.95	—	—	—	—	—	—
Silica	2.45	—	3.2	1.15	.85	1.15	{ 1.4	1.2	1.1	1.0	1.15	1.15
Organic Matter, etc.	—	—	—	—	1.53	—	{ 2.5	2.23	2.54	2.12	2.02	1.67
Total		35.0	102.0	106.0	21.0	29.0	27.0	26.0	24.7	22.7	23.5	17.7
Total Hardness		24	2	1.5	3	21	11.5	6	7	5.5	3	6
Free Ammonia		.002	.032	.002	.0290	.005	.0294	.0332	.0200	.0124	.0144	.0140
Albuminoid Ammonia		.005	.002	.002	.0008	.002	.0025	.0032	.0008	.0040	.0004	.0000
Oxygen Absorbed		.044	.018	.020	.035	.028	.060	.070	.100	.190	.030	.285

RESULTS OF ANALYSIS

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

UPPER AND MIDDLE OOLITES

Number	Source	561	562	563	564	565	566	567	568	569	570	571
		Swange, Dorset	Nr. Swindon, Wills.	Bridlington, Glos.	Dorchester, Oxon. 240 ft.	Dorchester, Oxon. 200 ft.	Thame, Oxon.	Bicester, Oxon.	Callow, Berks.	Renhold, Beds.	Bedford	Gosberton, Lincs.
Ferrous Carbonate		—	—	—	—	—	—	—	—	—	—	Fe .5
Calcium Carbonate		22.0	31.3	8.5	3.75	3.12	28.5	19.25	6.25	26.5	25.0	20.0
Calcium Sulphate		23.8	—	—	—	—	4.7	—	—	—	13.3	—
Calcium Chloride		—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		—	3.45	11.8	1.05	1.14	—	2.07	2.6	5.05	—	1.4
Magnesium Sulphate		6.4	—	4.9	—	—	.38	—	—	16.8	3.9	—
Magnesium Chloride		—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	14.05	—	34.5	35.02	—	8.8	41.4	—	—	1.9
Sodium Sulphate		.3	48.3 K ₂ SO ₄ 14.4	136.3	59.2	49.7	8.9	7.1	8.6	89.6 K ₂ SO ₄ 7.8	.75	8.5
Sodium Chloride		9.3	11.15	53.5	104.7	87.4	2.6	2.97	46.95 KCl 5.55	27.55	4.85	3.0
Sodium Nitrate		3.4	—	—	—	—	—	—	—	—	.8	—
Silica		.8	4.65	{ 1.5 3.5	1.5 .3	2.0 .62	1.2 .22	1.0 .81	3.15	.5	{ .7 .2	.8 .9
Organic Matter, etc.												

Total	66.0	127.3	220.0	205.0	179.0	46.5	42.0	114.5	173.8	49.5	36.5
Total Hardness	40	28	26	5	4.5	32	21.5	9	40	38	22
Free Ammonia	.004	.091	.1910	.1040	.0620	.0092	.0340	.087	.001	.0044	.0115
Albuminoid Ammonia	.005	.006	.0008	.0080	.0024	.0032	.0004	.006	.004	.0062	.0011
Oxygen Absorbed	.044	.040	.030	.040	.115	.045	.015	.116	.018	.063	.020

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

UPPER AND MIDDLE OOLITES, 572-576. LOWER OOLITE. BUCKS., 577-582

Number	Source	572	573	574	575	576	577	578	579	580	581	582
		Woodhall, Lincs.	Woodhall, Lincs.	Nr. Huntingdon. 320 ft.	Irton, Yorks.	Ferriby, nr. Hull, Yorks. 80 ft.	Stoke Goldston	Weston Underwood	Hanslope	Little Linford	Turweston	Wolverton
Ferrous Carbonate		—	—	Fe · 12	Trace	—	—	—	—	—	—	—
Calcium Carbonate		20.5	25.0	17.0	12.9	25.5	34.1	34.3	34.0	34.0	25.5	26.5
Calcium Sulphate		4.1	25.1	80.6	2.2	6.1	10.2	14.7	20.4	17.0	—	23.46
Calcium Chloride		215.2	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		—	—	—	—	—	—	—	—	—	—	—
Magnesium Sulphate		—	15.8	74.1	1.45	.5	3.0	6.3	9.9	1.0	1.9	—
Magnesium Chloride		144.2	—	—	—	—	1.5	—	—	2.7	—	.49
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate		—	29.6	251.6	.45	.44	—	—	7.5	—	5.85	.37
Sodium Chloride	NaBr 6.2	1741.5	434.0	759.0	3.95	4.62	1.5	7.0	9.6	3.8	4.6	5.12
Sodium Nitrate		—	—	1.2	.45	1.24	1.4	3.0	1.1	2.35	—	4.38
Silica		—	2.0	—	—	1.3	—	—	—	—	—	—
Organic Matter, etc.		—	—	—	.6	.3	3.0	2.7	2.5	2.65	1.1	1.1
Total	c. 2200	531.5	1200.0	22.0	40.0	54.7	68.0	85.0	63.0	47.9	62.0	62.0
Total Hardness		—	57.5	140	16	30	45	50	56	50	26	44
Free Ammonia		—	.0650	.5400	.000	.0040	.004	.002	.002	.004	.004	.0012
Aluminoid Ammonia		—	.0210	.0044	.002	.0010	.002	.002	.001	.006	.003	.0016
Oxygen Absorbed		—	.250	.285	.030	.009	.020	.030	.020	.060	—	.030

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LOWER OOLITE

Number	Source	583	584	585	586	587	588	589	590	591	592	593
		Etton, Hunts. 142 ft.	Kettering, Northants.	Buck- minster, Leicester	Buck- minster, Leicester	Harston, Leicester	Witney, Oxon.	Cirencester, Glos. 79 ft.	Bath, Somerset	Swinton, Wilts. 131 ft.	Swinton, Wilts. 231 ft.	Stamford, Linca.
Ferrous Carbonate		—	—	—	—	—	—	—	—	Trace	Trace	—
Calcium Carbonate		20.25	43.5	10.0	11.9	22.75	21.5	20.0	21.2	23.75	18.75	24.5
Calcium Sulphate		—	18.36	8.2	—	10.55	3.74	2.38	11.9	—	—	9.52
Calcium Chloride		—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	1.64	—	—	—	—	—
Magnesium Carbonate		3.5	—	—	—	—	—	—	.5	1.48	2.77	—
Magnesium Sulphate		—	9.88	2.4	—	1.5	—	2.47	—	.35	—	1.61
Magnesium Chloride		—	—	—	—	—	.59	—	—	—	—	1.25
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		5.05	—	—	.65	—	—	—	—	—	—	—
Sodium Sulphate		10.35	1.72	1.6	1.8	2.05	—	—	.6	5.21	6.51	—
						K_2SO_4						
						5.1						
Sodium Chloride		8.9	4.62	5.4	1.8	9.25	.76	1.65	2.7	1.98	6.27	1.43
Sodium Nitrate		.35	5.35	2.7	—	3.0	.85	1.57	2.9	—	—	4.3
Silica		2.5	1.57	.7	.35	2.8	.85	.55	1.2	.75	1.05	1.3
Organic Matter, etc.							.57	.38		.48	.97	.59
Total		50.9	85.0	31.0	16.5	57.0	30.5	29.0	41.0	34.0	40.0	44.5
Total Hardness		24	65	16	11.5	28	26	24	28.5	26	22	34
Free Ammonia		.0200	.0004	.002	.006	.000	.0000	.0000	.000	.0004	.0230	.0008
Albuminoid Ammonia		.0064	.0006	.004	.002	.001	.0004	.0000	.014	.0000	.0004	.0028
Oxygen Absorbed		.013	.010	.052	.064	.019	.015	.005	.034	.005	.005	.008

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LINCOLNSHIRE LIMESTONE. LOWER OOLITE. Lincs.

Number Source	594 Lincoln	595 Crowland	596 Market Deepling	597 Thurby	598 Thurby	599 Deepling St. James	600 Caythorpe	601 Caythorpe	602 Bourn	603 Stoke Park	604 Stroxton
Ferrous Carbonate	—	.3	—	—	—	—	1.75	—	—	—	—
Calcium Carbonate	22.0	5.5	8.65	23.7	24.0	8.15	34.75	20.0	22.8	13.7	22.0
Calcium Sulphate	11.6	—	—	3.4	6.45	—	—	16.3	10.2	5.8	5.8
Calcium Chloride	—	—	—	—	—	—	—	1.1	—	—	1.4
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	3.15	3.5	—	—	3.65	.65	—	—	—	—
Magnesium Sulphate	1.75	—	—	3.75	3.5	—	6.5	—	4.1	.5	—
Magnesium Chloride	—	—	—	—	—	—	—	2.0	.9	1.55	.95
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	50.75	20.3	—	—	22.1	—	—	—	—	—
Sodium Sulphate	—	16.3	8.7	4.6	1.65	9.3	25.45	—	—	—	—
Sodium Chloride	4.95	244.2	22.45	3.95	3.95	33.3	6.6	—	2.5	1.05	—
Sodium Nitrate	5.48	—	—	—	.35	—	—	4.35	.45	3.0	4.1
Silica	1.0	} 3.3	.4	1.1	1.1	2.0	.8	.75	.55	.4	.65
Organic Matter, etc.	.22		—	—	—	—	—	—	—	—	—
Total	47.0	323.5	64.0	40.5	41.0	78.5	76.5	44.5	41.5	31.0	35.0
Total Hardness	32	8.5	12.5	30	32	13	44	36	36	26	30
Free Ammonia	.0024	.160	.056	.004	.002	.080	.014	.000	.000	.003	.008
Albuminoid Ammonia	.0032	.002	.003	.003	.003	.001	.003	.006	.003	.005	.004
Oxygen Absorbed	.040	.083	.072	.039	.029	.025	.020	.032	.014	.032	.018

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LOWER OOLITE, 605. LIAS, 606-615

Number	605	606	607	608	609	610	611	612	613	614	615
Source	Metheringham, Lincs. 32 ft.	Welbourn, Lincs. 149 ft.	Sherborne, Dorset. 172 ft.	Sherborne, Dorset	Crompton Durville, Somerset	Stroud, Glos.	Shipton Moyné, Glos.	Shipton Moyné, Glos.	Makemore, Glos. 62 ft.	Upper Heyford, Oxon.	Quainton, Bucks.
Ferrous Carbonate	—	Trace	—	—	—	—	—	—	—	—	—
Calcium Carbonate	23.0	32.0	25.5	25.5	32.55	20.65	29.0	18.25	29.25	34.0	14.0
Calcium Sulphate	13.94	3.74	—	6.1	3.4	1.85	—	—	—	62.4	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	.42	—	—	—	3.65	.69	5.27	—	8.3
Magnesium Sulphate	1.21	3.71	1.38	.5	3.0	1.35	2.2	—	19.17	67.9	—
Magnesium Chloride	1.56	—	—	—	—	1.1	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	5.77	—	—	108.5
Sodium Sulphate	—	5.92	5.18	1.35	.7	—	9.95	7.7	1.64	13.0	216.0
Sodium Chloride	3.2	3.3	2.8	3.45	4.95	1.3	3.1	9.57	5.94	4.4	93.2
Sodium Nitrate	3.4	.85	.48	1.37	—	1.45	1.25	—	—	—	—
Silica	1.0	1.2	1.2	1.1	.6	1.1	1.25	{	1.3	—	1.1
Organic Matter, etc.	.69	.28	1.04	.13		—	—		.43	—	—
Total	48.0	51.0	38.0	39.5	45.2	28.8	50.4	44.0	63.0	c. 200	446.0
Total Hardness	36	38	26	30.5	38	21	32	19	52.5	c. 140	26
Free Ammonia	.0040	.0152	.0032	.0010	.001	.001	.024	.0280	.0220	—	.1620
Albuminoid Ammonia	.0028	.0064	.0006	.0042	.003	.001	.010	.0008	.0032	—	.0140
Oxygen Absorbed	.035	.075	.005	.056	—	.008	.084	.020	.055	—	.306

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

LIAS

Number	616	617	618	619	620	621	622	623	624	625	626
Source	County School, Bedford	Bedford Laundry	Bedford Brewery *	Ashwell, Rutland	Oakham, Rutland	Farthinghoe, Northants, 100 ft.	Brackley, Northants.	Leadenham, Lincs.	Nr. Grantham, Lincs.	Redcar, Yorks.	Redcar, Yorks.
Ferrous Carbonate	—	—	—	.1	—	—	Fe .12	—	Fe .6	Trace	—
Calcium Carbonate	19.3	25.0	30.8	29.0	36.0	16.5	21.25	37.0	.9	34.2	13.25
Calcium Sulphate	10.9	30.6	58.2	33.0	5.78	—	—	1.1	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	—	—	—	2.07	3.45	—	.48	.7	.5
Magnesium Sulphate	6.1	4.7	13.8	4.6	18.28	—	—	59.9	—	9.9	5.5
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	1.4
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	17.03	7.6	—	58.97	—	—
Sodium Sulphate	7.35	6.9	K ₂ SO ₄ 3.6 KCl 15.6	—	.8	8.88	23.7	186.9	29.6	19.85	—
Sodium Chloride	7.4	5.1	5.6	3.0	4.13	3.13	10.3	396.0	39.6	8.25	5.45
Sodium Nitrate	.3	6.6	4.8	.5	—	—	—	.4	—	—	—
Silica	.65	3.1	2.8	2.3	{ 1.25. .76	1.4	1.4	—	.8	1.7	.9
Organic Matter, etc. }						.49	.3	—	2.65		
Total	52.0	82.0	135.2	73.5	67.0	49.5	68.0	681.3	133.0	74.6	27.0
Total Hardness	33	52	121	56	56	19	28	90	1.5	48	22.5
Free Ammonia	.001	.006	.001	.010	.0036	.0190	.0340	—	.092	.020	.004
Albuminoid Ammonia	.013	.008	.011	.004	.0006	.0016	.0048	—	.006	.002	.029
Oxygen Absorbed	.126	.068	.125	.040	.010	.025	.060	—	.115	.007	.148

* Bedford Memoir.

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

NEW RED SANDSTONE. NOTTS.

Number Source	627 Kirkby	628 Newstead	629 Bulwell	630 Nr. Bulwell	631 Bestwood	632 Papplewick	633 Nr. Newark	634 Epperstone	635 Nr. Retford	636 Southwell	637 Burton Joyce
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	6.6	11.5	11.0	12.0	7.5	4.5	6.7	4.5	9.0	3.62	4.5
Calcium Sulphate	—	1.35	8.1	15.6	.7	.51	1.0	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	—	—	—	—	—	7.3	8.3	2.01	10.55
Magnesium Sulphate	3.0	5.4	7.9	2.65	1.0	4.19	1.05	.75	3.9	.59	2.01
Magnesium Chloride	1.8	2.3	3.1	10.75	1.15	1.76	2.0	1.9	—	—	1.32
Magnesium Nitrate	—	—	—	—	—	—	—	.55	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	—	—	—	—	—	—	—	—	.45	.72	—
Sodium Chloride	—	1.5	1.15	6.7	1.9	.64	.35	—	2.6	1.98	.12
Sodium Nitrate	3.95	4.1	6.2	5.3	4.1	2.55	4.95	—	.3	1.2	—
Silica	1.15	.35	1.55	1.5	.65	.85	.95	2.0	1.45	.7	.9
Organic Matter, etc.	—	—	—	—	—	.7	—	—	—	.18	2.1
Total	16.5	26.5	39.0	54.5	17.0	15.7	17.0	17.0	26.0	11.0	21.5
Total Hardness	9	21	31	39	10	10.5	14	15	25	8	21.5
Free Ammonia	.000	—	—	—	—	.0000	.004	—	.003	.0020	.0000
Albuminoid Ammonia	.005	—	—	—	—	.0000	.001	—	.002	.0008	.0000
Oxygen Absorbed	.009	—	—	—	—	.010	—	—	—	.008	.000

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

NEW RED SANDSTONE. YORKS.

Number Source	638 Cattal	639 Goole	640 Gatesforth	641 Brayton	642 Selby	643 Selby	644 Nr. Selby	645 Goole	646 Tadcaster	647 Roall	648 Rical
Ferrous Carbonate	—	·3	—	—	—	—	—	—	—	—	·9
Calcium Carbonate	27·5	32·35	12·75	10·75	13·25	22·0	11·0	5·85	25·5	5·5	21·15
Calcium Sulphate	—	—	—	—	—	—	—	2·55	1·0	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	2·25	5·4	3·3	1·45	5·7	11·25	—	—	—	—	5·45
Magnesium Sulphate	6·9	6·5	1·75	2·0	·65	8·65	4·4	·75	7·3	—	—
Magnesium Chloride	3·8	—	—	2·15	2·0	—	1·95	2·55	·8	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	—	5·0	·9	—	—	11·25	—	—	—	4·15	6·35
Sodium Chloride	·4	8·7	2·6	—	1·4	6·6	·25	—	4·05	3·55	4·0
Sodium Nitrate	3·3	—	2·05	4·5	3·2	—	5·5	3·85	2·5	3·1	3·8
Silica	1·85	1·45	·65	·85	·8	·25	·9	·95	1·35	5·2	·9
Organic Matter, etc.	—	—	—	—	—	—	—	—	—	·2	·75
Total	46·0	59·7	24·0	21·7	27·0	60·0	24·0	16·5	42·5	25·0	43·3
Total Hardness	34·5	41	18·5	14	24	44	16	12	30	12	25
Free Ammonia	·000	·112	·000	·003	—	—	·000	—	·000	—	—
Albuminoid Ammonia	·004	·010	·002	·001	—	—	·002	—	·004	—	—
Oxygen Absorbed	·020	·124	·012	·026	—	—	·018	—	·030	—	—

RESULTS OF ANALYSIS

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

NEW RED SANDSTONE. YORKS., 649-653. WARWICK, 654-659

Number	649	650	651	652	653	654	655	656	657	658	659
Source	Thorne	Burn	Nr. Pontefract	Nr. Pontefract	Doncaster	Leamington	Leamington	King's Norton 1,263 ft.	Nuneaton. 240 ft.	Birmingham. 420 ft.	Birmingham. 750 ft.
Ferrous Carbonate	3.7	—	—	—	—	—	—	—	—	—	Trace
Calcium Carbonate	26.75	10.0	8.5	4.25	7.5	26.3	18.3	11.5	19.5	15.6	6.5
Calcium Sulphate	—	—	1.15	—	—	—	—	—	15.64	8.5	51.68
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	15.75	3.1	—	2.6	6.32	1.1	4.9	9.25	—	—	—
Magnesium Sulphate	—	.25	2.5	—	.69	9.4	4.5	2.7	12.35	7.52	14.45
Magnesium Chloride	—	.95	1.95	—	1.33	—	—	—	—	1.3	.66
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	5.05	—	—	32.6	—	—	—	—	—	—	—
Sodium Sulphate	6.2	—	—	2.95	—	5.9	—	5.7	9.79	—	—
Sodium Chloride	4.95	1.0	.25	12.0	.35	3.9	2.65	2.95	5.61	4.17	.9
Sodium Nitrate	—	.9	2.49	—	.25	—	1.25	—	—	5.48	—
Silica	.6	1.3	{ 1.5	2.0	1.2	{ .2		{ 1.5	1.35	1.0	.85
Organic Matter, etc.	—	—	.06	1.3	.36	—		.4	2.26	—	1.96
Total	63.0	17.5	18.4	57.6	18.0	46.8	32.0	34.0	66.5	43.6	77.0
Total Hardness	46	15	13.5	7.5	17.5	40	30	25	42	31	58
Free Ammonia	.052	—	.0040	.0480	.0004	.006	.003	.0048	.0104	.0010	.0104
Albuminoid Ammonia	.002	—	.0012	.0028	.0008	.003	.003	.0036	.0000	.0022	.0016
Oxygen Absorbed	.028	—	.015	.035	.015	.020	.014	.045	.030	.009	.020

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

NEW RED SANDSTONE, LANCs., 660-666. LINCs., 667-670

Number	660	661	662	663	664	665	666	667	668	669	670
Source	Bicker- staffe	Aughton	Scarth Hill	Springfield	Halsall	Nr. Warrington 1	Nr. Warrington 2	Crowle	Crowle	Crowle, 470 ft.	Crowle, 690 ft.
Ferrous Carbonate	—	—	—	—	—	—	—	Trace	—	—	—
Calcium Carbonate	26.5	15.0	1.5	19.0	14.75	11.0	13.75	8.3	22.4	28.0	7.5
Calcium Sulphate	—	—	4.08	—	—	—	—	92.9	—	81.0	142.8
Calcium Chloride	—	—	—	—	—	—	—	.7	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	2.95	3.37	—	5.48	3.58	4.9	1.35	—	12.95	—	—
Magnesium Sulphate	14.08	6.77	6.42	9.48	6.27	—	3.6	—	40.0	16.0	6.5
Magnesium Chloride	—	1.8	.78	—	—	—	1.2	30.75	—	36.0	39.5
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	—	—	—
Sodium Sulphate	3.06	—	—	3.02	.41	4.0	—	—	12.3	—	—
Sodium Chloride	3.63	1.91	3.5	5.12	4.29	2.8	2.45	23.65*	32.5	40.7	67.0
Sodium Nitrate	—	.97	4.39	—	.37	1.2	2.3	—	21.55	—	—
						KNO ₃ 24.35					
Silica	1.5	1.0	.9	1.1	1.1	.9	1.55	3.7	1.95	1.2	1.3
Organic Matter, etc.	.28	1.18	.43	.3	.73		—	—	—	2.1	5.4
Total	52.0	32.0	22.0	43.5	31.5	24.8	26.2	160.0	168.0	205.0	270.0
Total Hardness	42	27	11	34	25	16	18	110	90	140	160
Free Ammonia	.0028	.0024	.0012	.0016	.0000	.005	.002	.018	.000	.0084	.0120
Albuminoid Ammonia	.0024	.0008	.0008	.0004	.0000	.001	.003	.004	.014	.0014	.0014
Oxygen Absorbed	.070	.010	.010	.005	.005	.015	.028	.018	.124	.010	.010

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

NEW RED SANDSTONE. Lincs., 671-676. CHESHIRE, 677-681

Number	671	672	673	674	675	676	677	678	679	680	681
Source	Nr. Lincoln 1	Nr. Lincoln 2	Gainsborough, 1,352 ft.	Gainsborough, 1,515 ft.	Gainsborough, 1,634 ft.	Gainsborough, 1,000 ft.	Ellesmere Port	Hooton	Preston	Mouldsworth, 250 ft.	Mouldsworth, 800 ft.
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	7.7	8.0	17.2	16.8	16.5	10.0	22.0	16.5	14.0	17.0	17.0
Calcium Sulphate	121.2	118.3	50.6	3.4	1.02	41.48	—	—	—	7.8	—
Calcium Chloride	43.2	11.8	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	—	—	—	—	—	5.85	8.7	3.37	—	.42
Magnesium Sulphate	—	—	12.3	7.9	17.29	12.84	—	—	3.76	.63	6.02
Magnesium Chloride	62.5	39.5	—	—	—	—	—	—	1.47	15.52	2.19
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	36.2	17.5	.73	.71	4.8	3.8	—	—	—
Sodium Sulphate	—	—	7.2	4.6	3.8	5.12	9.7	5.5	5.2	77.95	29.98
Sodium Chloride	150.65	—	—	—	—	—	—	—	—	—	—
	KCl 11.45	—	2.5	—	—	—	1.3	—	1.44	.6	.6
Sodium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Silica	—	—	1.0	1.8	{ 1.05	{ 1.55	{ 1.55	{ 1.1	1.2	1.8	1.4
Organic Matter, etc. }	13.3	—	—	—	{ 2.11	{ 1.3	—	.2	1.56	1.7	.39
Total	410.0	177.6	127.0	52.0	42.5	73.0	45.2	35.8	32.0	123.0	58.0
Total Hardness	—	—	—	26	32	52	28	27	23.5	44	26
Free Ammonia	—	—	—	—	.0056	.0210	.0010	.0010	.0036	.0032	.0036
Albuminoid Ammonia	—	—	—	—	.0000	.0038	.0015	.0010	.0004	.0008	.0016
Oxygen Absorbed	—	—	—	—	.005	.070	.017	.003	.005	.010	.025

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

NEW RED SANDSTONE												
Number	Source	682	683	684	685	686	687	688	689	690	691	692
		Rugeley, Staffs.	The Potteries, Staffs.	The Potteries, Staffs. 750 ft.	Stone, Staffs.	Chilcote, Staffs.	Ilkeston, Derby	Long Eaton, Derby. 400 ft.	Frome, Somerset. 300 ft.	Avonmouth, Glos.	Worcester. 105 ft.	Harpole, Northants. 107 ft.
Ferrous Carbonate		—	—	—	—	—	BaCO ₃ 1.0	—	—	—	—	—
Calcium Carbonate		8.5	14.0	9.4	18.0	21.25	3.0	20.5	2.25	59.16	12.5	21.0
Calcium Sulphate		127.2	—	—	—	—	—	5.1	—	41.15	67.15	6.46
Calcium Chloride		—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		—	3.0	3.45	.42	3.16	7.0	—	.7	—	—	—
Magnesium Sulphate		19.8	2.0	3.76	4.78	13.28	—	19.56	—	77.7	13.3	4.31
Magnesium Chloride		—	—	.94	—	—	—	.94	—	90.95	2.0	.47
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	—	—	—	—	13.6	—	25.9	—	—	—
Sodium Sulphate		9.9	—	—	1.48	5.63	—	—	7.7	—	—	—
Sodium Chloride		2.6	2.2	.82	2.14	14.0	10.5	.99	10.5	1069.4	13.5	2.9
Sodium Nitrate		2.3	2.3	1.58	—	.36	—	—	—	.4	8.5	—
Silica		5.7	1.0	.7	1.0	.8	.9	.9	1.4	1.15	1.2	1.35
Organic Matter, etc.		—	1.3	.35	.68	1.12	—	.81	2.05	10.0	1.85	.51
Total		176.0	25.8	21.0	28.5	59.6	36.0	48.8	50.5	1350.0	120.0	37.0
Total Hardness		110	19.5	18	22	36	12	42	3	285	75	30
Free Ammonia		.003	—	.0010	.0004	.0560	—	.0012	.0330	.0480	.0032	.0010
Albuminoid Ammonia		.004	—	.0008	.0008	.0008	—	.0000	.0016	.0070	.0018	.0016
Oxygen Absorbed		—	.008	.000	.005	.005	—	.000	.0025	.072	.025	.0035

RESULTS OF ANALYSIS

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

MAGNESIAN LIMESTONE, 693-697. COAL MEASURES, 698-703

Number	693	694	695	696	697	698	699	700	701	702	703
Source	Hartlepool, Durham	Nr. Hartlepool 1	Nr. Hartlepool 2	Nr. Hartlepool 3	Nr. Sunderland, Durham	Doncaster, Yorks.	Adwick-le- Street, Yorks.	Barnsley, Yorks.	Wath-upon- Dearne, Yorks.	Swincon, Yorks. 100 ft.	Stowheath, Staffs.
Ferrous Carbonate	—	—	—	—	—	—	—	—	Mn .27	—	—
Calcium Carbonate	25.0	27.5	28.5	30.0	21.25	25.0	27.5	9.0	23.0	29.0	38.0
Calcium Sulphate	5.4	11.2	25.9	1.55	—	—	1.36	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	3.6	18.5	—	11.4	—	9.27	12.25
Magnesium Carbonate	—	—	—	—	14.67	1.97	24.37	—	27.08	26.33	—
Magnesium Sulphate	22.8	16.4	25.95	24.0	2.07	—	5.35	—	2.82	—	—
Magnesium Chloride	2.35	5.5	8.8	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	21.8	—	—	9.45
Sodium Carbonate	—	—	—	2.5	—	3.44	—	3.55	—	2.37	79.9
Sodium Sulphate	13.3	17.8	33.75	13.85	5.54	9.4	3.33	11.6	36.8	7.59	17.5
Sodium Chloride	—	1.75	1.2	1.95	1.92	—	3.01	—	—	—	—
Sodium Nitrate	1.0	1.45	1.9	1.15	1.2	1.2	.5	2.1	1.4	1.2	—
Silica	.15	—	—	—	1.75	1.1	.58	.55	2.4	.74	.9
Organic Matter, etc.	—	—	—	—	—	—	—	—	—	—	—
Total	70.0	81.6	126.0	75.0	52.0	60.6	65.0	60.0	93.5	76.5	158.0
Total Hardness	52	55	64	45	40	48.5	55	23	50	60	52
Free Ammonia	.0040	.060	.012	.000	.0000	.0072	—	.0616	.2200	.0074	.026
Aluminoid Ammonia	.0004	.002	.001	.001	.0000	.0032	—	.0016	.0096	.0000	.003
Oxygen Absorbed	.005	.027	.008	.018	.005	.055	—	.106	.380	.015	.006

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

COAL MEASURES

Number	704	705	706	707	708	709	710	711	712	713	714
Source	Acrington, Lanes. 360 ft.	Acrington, Lanes.	Acrington, Lanes. 150 ft.	Duxbury, Lanes.	Nr. Bury, Lanes.	Stourport, Worcs.	Nr. Bristol, Glos.	Nr. Bristol, Glos.	Nr. Bristol, Glos.	Nr. Bristol, Glos.	West Gloucester
Ferrous Carbonate	—	—	—	Fe .36	1.2	—	—	—	Trace	—	—
Calcium Carbonate	11.0	10.0	19.37	27.0	7.5	22.5	44.5	17.0	30.5	33.5	29.2
Calcium Sulphate	—	—	—	23.65	19.0	—	—	—	4.4	—	1.0
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	1.7	6.5	2.62	—	—	3.5	5.9	4.6	—	3.45	—
Magnesium Sulphate	—	—	—	31.6	4.0	—	—	—	20.0	—	15.3
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	18.0	6.9	6.92	—	—	83.25	7.2	5.9	—	7.85	—
Sodium Sulphate	1.48	7.7	5.9	—	17.8	35.5	74.9	15.9	6.15	48.2	5.3
Sodium Chloride	4.45	3.3	3.3	3.6	1.65	58.0	21.1	7.2	5.95	11.55	4.5
Sodium Nitrate	.55	.7	—	.55	—	—	—	—	—	—	—
Silica	1.4	1.0	1.1	1.6	4.85	5.25	1.6	2.4	2.8	3.55	.8
Organic Matter, etc.	.4	1.4	.79	1.0		—	—	—	—	—	—
Total*	39.0	37.5	40.0	89.0	56.0	208.0	155.2	53.0	69.8	108.1	56.1
Total Hardness	12.5	18	23	75	30	30	53	22	60	40	44
Free Ammonia	.0084	.0020	.0160	.0210	—	.040	.030	—	.003	.036	—
Albuminoid Ammonia	.0032	.0006	.0012	.0026	—	.003	.002	—	.004	.008	—
Oxygen Absorbed	.040	.020	.010	.050	—	.020	.022	—	.020	.071	.035

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
COAL MEASURES, 715-718. MILLSTONE GRIT, 719-724

Number	715	716	717	718	719	720	721	722	723	724
Source	Rhymney, Glam.	Tilmanstone, Kent 600 ft.	Tilmanstone, Kent 1,140 ft.	Morpeth, Northumber- land	Bolton, Lancs. 178 ft.	Bolton, Lancs. 230 ft.	Lancaster, 265 ft.	Lancaster	Rhymney Valley Glam.	Rhymney Valley Glam.
Ferrous Carbonate	—	—	—	—	Fe .12	.26	—	—	—	—
Calcium Carbonate	13.0	2.5	4.0	5.38	5.12	11.5	14.0	.5	1.0	1.35
Calcium Sulphate	—	—	—	—	—	—	—	1.15	1.2	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	4.2	1.5	2.4	1.74	2.43	4.15	1.05	—	—	—
Magnesium Sulphate	5.4	—	—	—	—	—	—	—	.95	.8
Magnesium Chloride	—	—	—	—	—	—	—	.5	.3	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	39.65	42.3	55.7	12.2	5.9	1.85	—	—	—
Sodium Sulphate	—	8.9	26.2	.74	2.05	2.35	2.8	—	—	—
Sodium Chloride	3.0	34.3	49.8	7.91	1.4	1.8	3.8	.7	1.6	2.35
Sodium Nitrate	—	—	—	—	—	—	—	.25	.1	—
Silica	—	.15	—	{ .5	1.1	1.2	2.0	1.1	.25	—
Organic Matter, etc.	.6	—	—	{ 1.53	—	1.1	—	—	—	—
Total	26.2	87.0	124.7	73.5	24.3	28.0	25.5	4.2	5.4	4.5
Total Hardness	20	4.5	9	8.5	8.5	17	19	2	3.5	2
Free Ammonia	.003	.0140	.0080	.0320	.0096	.0140	.128	.002	.000	.001
Albuminoid Ammonia	.004	.0025	.0020	.0052	.0003	.0024	.002	.006	.003	.011
Oxygen Absorbed	.050	.050	.085	.035	.005	.050	.007	118	.031	.154

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CARBONIFEROUS LIMESTONE

Number	Source	725	726	727	728	729	730	731	732	733	734	735
		Trefill Brook, Mon.	Shon Sheffray Spring, Mon.	Nr. Pontypool, Mon.	Bakewell, Derby	Downside, Somerset	Swarland, Northumber-land	Seahouses, Northumber-land	Berwick-on-Tweed, 500 ft.	Berwick-on-Tweed	Mallow, Cork	Carriek, Ireland
Ferrous Carbonate		—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate		6.4	6.5	9.0	18.5	27.0	20.0	28.0	3.75	17.25	10.65	25.3
Calcium Sulphate		—	—	—	37.4	—	—	—	.34	—	5.9	—
Calcium Chloride		—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate		—	—	.85	—	.84	9.7	.42	—	.63	—	2.8
Magnesium Sulphate		1.05	1.05	1.75	11.1	1.26	4.45	9.05	2.71	7.15	3.8	1.45
Magnesium Chloride		1.1	.95	—	1.2	—	2.7	3.13	1.17	10.83	—	—
Magnesium Nitrate		—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate		—	—	.6	—	1.77	—	—	—	—	—	1.35
Sodium Sulphate		—	—	2.0	2.95	1.8	.5	9.36	2.85	12.44	5.35	4.3
Sodium Chloride		.3	.25	.8	—	.73	—	—	1.95	1.7	7.8	1.1
Sodium Nitrate		—	—	—	—	{ 1.2	.8	1.25	1.2	1.1	1.3	.9
Silica		1.35	.45	.8	1.85	{ 1.4	1.85	.81	.53	1.4		
Organic Matter, etc.		—	—	—	—	—	—	—	—	—	—	—
Total		12.2	11.2	15.8	73.0	36.0	40.0	52.0	14.5	52.5	34.8	37.2
Total Hardness		7	7	11	60	30	40	40	7.5	35	21	32
Free Ammonia		.011	.000	.000	—	.0012	.0036	.0152	.0000	.0000	.001	.006
Aluminoid Ammonia		.022	.006	.011	—	.0006	.0000	.0004	.0000	.0000	.007	.004
Oxygen Absorbed		.358	.106	.160	—	.010	.030	.015	.000	.000	.047	.040

RESULTS OF ANALYSIS

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

CARBONIFEROUS LIMESTONE, 736-737. OLD RED SANDSTONE, 738-741. OLDER ROCKS, 742-746

Number	736	737	738	739	740	741	742	743	744	745	746
Source	Tipperary, Ireland	Greybridge, Ireland	Wells, Somerset	Monmouth	Above Pontypool	Middleton, Cork	Malvern	Llandrindod Wells	Truro, Cornwall, 235 ft.	Kelso, Roxburgh	Floors Castle, Kelso
Ferrous Carbonate	—	—	—	—	—	—	—	2.3	—	—	—
Calcium Carbonate	26.0	28.5	16.9	15.5	7.5	4.6	9.15	14.8	5.25	19.2	1.25
Calcium Sulphate	—	—	—	—	—	—	—	9.8	—	39.7	—
Calcium Chloride	—	—	—	—	—	—	—	158.4	—	142.9	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	2.8	4.15	1.75	3.1	4.8	.6	1.45	—	6.06	—	.15
Magnesium Sulphate	3.3	—	12.3	2.95	—	.8	4.0	—	—	—	—
Magnesium Chloride	—	—	—	—	—	.8	5.15	53.9	—	62.6	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	—	—	—	—	—	—	—	3.26	—	25.15
Sodium Sulphate	.85	1.2	33.3	2.45	2.8	—	—	—	3.11	—	1.95
Sodium Chloride	6.25	4.8	2.3	3.15	2.0	2.3	6.8	233.8	4.79	721.2	3.45
								NaBr .85	—	—	—
Sodium Nitrate	2.2	.9	1.23	1.25	.2	1.6	1.0	—	—	—	.4
Silica	1.2	.45	{ .9	{ 2.0	{ .5	{ .1	{ .05	{ 19.15	{ 1.05	{ 4.4	{ 2.15
Organic Matter, etc.			{ .32						{ 1.18		
Total	42.6	40.0	69.0	30.4	17.8	10.8	27.6	493.0	24.7	990.0	34.5
Total Hardness	32	28	31	19.5	12	7	19	—	13	—	2
Free Ammonia	.005	.001	.0180	.002	.001	.001	.006	—	.0036	—	.010
Albuminoid Ammonia	.002	.001	.0002	.002	.002	.006	.008	—	.0068	—	.004
Oxygen Absorbed	.020	.000	.005	.020	.020	.053	.072	—	.260	—	.052

RESULTS OF WATER ANALYSES IN PARTS PER 100,000
FOREIGN WATERS. RIVERS, 747-753. SPRINGS, 754-757

Number	747	748	749	750	751	752	753	754	755	756	757
Source	R. Seine, above Paris	R. Svarta, Sweden	R. Jordan, Palestine	R. Tigris, Iraq	R. Euphrates, Iraq	Shatt al Arab River, Iran	Ras al Ain Springs, Tel Aviv	R. Ain Miriam, Jerusalem	Ras al Ain Springs, Tel Aviv	Guadalquivir, Spain	Incheux, France
Ferrous Carbonate	18.4	—	—	—	—	—	—	—	—	—	.5
Calcium Carbonate	1.85	3.5	13.5	13.5	11.5	12.0	10.5	18.75	18.63	0.55	23.75
Calcium Sulphate	—	—	—	—	—	4.1	3.4	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	.55	.84	.42	1.69	—	—	—	—	—	—
Magnesium Sulphate	1.0	—	11.29	9.29	8.94	9.88	5.4	6.11	5.77	0.77	.69
Magnesium Chloride	—	—	3.4	—	—	—	—	—	2.58	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	1.0	—	—	—	.17	—	.6	—	—	.62
Sodium Sulphate	—	1.3	32.79	2.35	2.77	14.85	19.14	27.0	25.21	—	.89
Sodium Chloride	2.0	—	—	3.3	9.57	—	—	—	—	2.8	KCl .65
Sodium Nitrate	1.1	.1	1.7	—	—	—	—	1.2	—	—	1.23
Silica	.45	.65	{ 1.2	.8	1.0	2.0	1.1	1.1	1.2	.4	1.6
Organic Matter, etc.	—	—	{ .28	.34	.53	1.0	.86	1.46	2.32	.48	—
Total	24.8	7.1	65.0	30.0	36.0	44.0	40.4	62.0	61.5	5.0	30.0
Total Hardness	20	3.5	28	22	21.5	24	17.5	31	33	1.25	24.5
Free Ammonia	.008	.005	.0060	.0008	.0016	.0008	.0008	.0012	.0008	.0016	.0009
Albuminoid Ammonia	.011	.020	.0044	.0032	.0064	.0200	.0110	.0018	.0008	.0072	.0011
Oxygen Absorbed	.090	.280	.050	.040	.070	.180	.150	.040	.020	.110	.010

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

FOREIGN WATERS. SPRINGS, 758-759. BOREHOLES. ARABIA, 760-761. IRAK, 762-768

Number	758	759	760	761	762	763	764	765	766	767	768
Source	Reval, Esthonia	Azrak, Irak	Aden, 140-200 ft.	Aden, 1,600 ft.	Ruthbah, 315 ft.	Haffa, 62 ft.	Furkhus, 45 ft.	Araq, 125 ft.	Wadi Miyah, 225 ft.	Wadi Hauran, 405 ft.	Wadi Hahwahshed, 515 ft.
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	9.0	3.0	8.0	6.25	11.5	11.75	15.75	14.5	14.0	31.0	13.5
Calcium Sulphate	—	—	—	—	—	—	—	2.38	6.46	15.64	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	1.98	2.77	8.43	3.31	6.32	9.48	.63	—	—	—	2.77
Magnesium Sulphate	—	—	22.57	—	1.88	2.32	24.8	11.86	9.88	39.52	—
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	—	3.95	—	14.1	—	—	—	—	—	—	.76
Sodium Sulphate	.89	5.62	8.9	17.2	12.0	5.25	6.25	6.01	.83	.95	2.96
Sodium Chloride	1.07	8.75	39.6	76.9	12.7	9.24	17.16	5.45	18.48	14.85	4.13
Sodium Nitrate	.3	1.95	12.8	—	1.7	1.23	1.45	.85	2.55	—	.85
Silica	1.2	1.4	3.6	3.0	1.2	1.0	1.0	1.1	1.1	1.5	1.2
Organic Matter, etc.	.16	.56	.5	1.24	1.7	.73	.96	.35	.7	1.54	.33
Total	14.6	28.0	104.4	122.0	49.0	41.0	68.0	42.5	54.0	105.0	26.5
Total Hardness	11.5	6.5	38	10	21	26	38	26	28	77.5	17
Free Ammonia	.0424	.0064	.0010	.0024	.0026	.0044	.0022	.0032	.0020	.0004	.0020
Albuminoid Ammonia	.0850	.0016	.0032	.0104	.0004	.0080	.0012	.0008	.0008	.0012	.0008
Oxygen Absorbed	.590	.025	.065	.175	.015	.110	.015	.015	.015	.020	.015

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

FOREIGN BOREHOLE WATERS. FLANDERS. LANDENIEN SAND, 769-776. CHALK, 777-779

Number	769	770	771	772	773	774	775	776	777	778	779
Source	Steenvoorde. 600 ft.	Nr. Casel. 390 ft.	Ploegsteert. 289 ft.	Meteren. 550 ft.	Nr. Caestre. 300 ft.	Estaires. 210 ft.	Poperinghe. 485 ft.	Roubrugge. 400 ft.	Nr. Baillien. 680 ft.	Caestre. 490 ft.	Estaires. 445 ft.
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	2.5	9.2	1.95	2.13	2.2	8.87	2.37	1.37	2.37	3.0	15.5
Calcium Sulphate	—	—	—	—	—	—	—	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	—	3.8	.86	.69	.9	4.15	—	.41	1.04	.52	3.8
Magnesium Sulphate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Chloride	—	—	—	—	—	—	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	43.12	23.7	28.16	27.65	34.57	3.94	43.13	58.54	30.14	32.78	5.3
Sodium Sulphate	13.62	11.4	35.54	11.55	11.55	30.8	33.46	26.06	47.4	13.47	41.5
Sodium Chloride	21.27	8.4	42.71	43.87	23.09	53.93	43.87	42.55	65.6	26.22	71.9
Sodium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Silica	1.59	1.5	1.28	2.11	.69	.81	1.17	3.57	3.95	2.01	1.0
Organic Matter, etc.	—	—	—	—	—	—	—	—	—	—	—

Total	82.5	58.0	110.5	88.0	73.0	102.5	124.0	132.5	150.5	78.0	139.0
Total Hardness	2.5	12	3.5	3	3	16.5	2	2	4	4	21
Free Ammonia	.0260	.0120	.0280	.0220	.0220	.0950	.0190	.0220	.0160	.0160	.0280
Albuminoid Ammonia	.0060	.0050	.0010	.0040	.0030	.0100	.0022	.0030	.0030	.0060	.0250
Oxygen Absorbed	.062	.030	.055	.015	.033	.125	.074	.058	.041	.085	.120

RESULTS OF WATER ANALYSES IN PARTS PER 100,000

FOREIGN BOREHOLE WATERS. FLANDERS. CHALK, 780-784.

N. FRANCE. CHALK AT OR NEAR OUTCROP, 785-788. COAL MEASURES, 789-790

Number Source	780 Estaires. 390 ft.	781 Doulien. 393 ft.	782 Merville. 470 ft.	783 Bac St. Maur. 425 ft.	784 Rexpoede. 750 ft.	785 Iumbres. 280 ft.	786 Esquerdes. 190 ft.	787 Bolsdinghem. 373 ft.	788 Assinghem. 141 ft.	789 Armentieres. 940 ft.	790 Bailleul. 980 ft.
Ferrous Carbonate	—	—	—	—	—	—	—	—	—	—	—
Calcium Carbonate	7.37	5.5	1.85	6.87	1.5	25.0	23.5	21.5	21.55	3.25	5.5
Calcium Sulphate	—	—	—	—	—	.68	.34	—	—	—	—
Calcium Chloride	—	—	—	—	—	—	—	—	—	—	—
Calcium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Magnesium Carbonate	2.94	2.6	.9	3.46	—	—	—	7.17	1.01	1.4	2.94
Magnesium Sulphate	—	—	—	—	—	—	—	.64	2.47	—	—
Magnesium Chloride	—	—	—	—	—	.39	—	—	—	—	—
Magnesium Nitrate	—	—	—	—	—	—	—	—	—	—	—
Sodium Carbonate	6.17	10.26	22.35	10.12	59.62	—	—	—	—	27.7	23.52
Sodium Sulphate	28.43	24.87	9.5	53.75	17.77	—	.35	.57	.19	35.55	171.77
Sodium Chloride	54.26	56.07	41.25	79.33	29.03	2.49	2.63	4.94	2.8	27.55	114.8
Sodium Nitrate	—	—	—	—	—	.72	1.03	.48	.23	—	—
Silica	—	—	—	—	—	—	—	—	—	—	—
Organic Matter, etc. }	.83	1.2	2.65	1.47	2.08	.72	1.15	.7	.75	2.05	1.42

Total	100.0	100.5	78.5	155.0	110.0	30.0	29.0	36.0	29.0	97.5	320.0
Total Hardness	12	8	3.5	11.5	1.5	28	24	31	27	7	8.5
Free Ammonia	.0210	.0080	.0000	.0340	.0180	.0030	.0030	.0000	.0020	.0080	.0480
Aluminoid Ammonia	.0030	.0050	.0030	.0000	.0040	.0020	.0026	.0020	.0030	.0040	.0030
Oxygen Absorbed	.051	.043	.025	.090	.065	.017	.083	.063	.054	.032	.042

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PART VII

THE BACTERIOLOGICAL EXAMINATION OF WATER

CHAPTER XXVI

THE VALUE AND SIGNIFICANCE OF THE BACTERIOLOGICAL EXAMINATION

THE primary object of the bacteriological examination of water is the detection of faecal pollution. Ill-health caused by the consumption of water arises only in rare instances from the presence of an excess of one or other of the inorganic salts which water may contain, and is comparatively seldom due to metallic matter such as lead, etc. What constitutes a much greater danger to health is the presence of excremental bacteria, as water so contaminated may convey the causative organisms of disease. The danger of polluted water comes from living organisms and not from dead organic matter. What is most feared in a water supply is the possible presence therein of pathogenic bacteria, such as typhoid bacteria, and the duties of water authorities are very largely concerned with the prevention of such contamination, or its effective removal by treatment.

Before adequate information is available on which to form an opinion regarding the purity of a water and its suitability for drinking purposes, it is necessary to have a knowledge of the source and history of the water and of the results of both chemical and bacteriological examinations, the latter being particularly important.

A great deal of valuable information concerning the sanitary quality of a water is undoubtedly obtained by chemical analysis, and many sources of pollution are detected by this method. Also, it is generally true that, under natural conditions, a water which on chemical analysis shows evidence of recent pollution is at the same time bacterially impure. It does not by any means follow, however, that a water of satisfactory chemical and organic quality is free from dangerous bacteria and safe to drink. Organic matter, admittedly, is food supply for bacteria and favours their multiplication, but large numbers of bacteria may be found in water of the highest standard of organic purity. As compared with chemical methods of analysis, bacteriology affords much greater delicacy and gives more exact information of the presence in water of excremental matter. Many instances have occurred in our experience where repeated chemical analysis of a water supply has failed to reveal any evidence of pollution which nevertheless existed and was well

demonstrated by bacteriological methods. There are, in fact, many communities which would be exposed to considerable danger if the water supplies thereto were judged solely on chemical analyses.

On the other hand, uniformly good bacteriological results are trustworthy, because it is extremely rare, under natural conditions, for a water to contain pathogenic bacteria without giving well-marked adverse results in the routine bacteriological examination. Actually, in many water supplies, whose origin and history are known, routine control of purity is maintained by bacteriological examination, chemical analysis being applied only occasionally or for special purposes.

With few exceptions, all waters at some period in their history come into contact with, and acquire, sewage or manurial matters. Chemical analysis affords valuable information of past or remote pollution, but cannot be trusted to reveal all forms of recent pollution. Bacteriological examinations give less information of the remote history of the water but, what is much more important, they disclose the immediate or near antecedents with reasonable ease, and with greater reliability than chemical analyses.

The results of the chemical and bacteriological examinations should always be correlated, and an opinion should never be expressed on the purity of a water, however good the results of the chemical analysis, without a knowledge of its bacteriology. Disease has been caused by water of satisfactory chemical and organic purity, and it is common knowledge that many water supplies of great organic purity are to-day submitted to processes of treatment, such as chlorination, on account of evidence of pollution provided solely by bacteriological examinations. An example of our experience can be cited.

Paratyphoid fever made its appearance in a certain district, all efforts to trace the mode of spread failed, and cases continued to occur over a long period of time. The water supply, derived from deep wells in the Chalk, was of the highest repute, of great organic purity, and no change in the chemical analyses could be observed. Circumstances, however, compelled the medical officer of health to suspect the water supply and bacteriological examinations were made. Fæcal organisms (*Bact. coli*) were found in 1 c.c. and smaller quantities of the water. Chlorination was introduced, and the presence of paratyphoid fever in the district then came to an end. The circumstances were, to say the least, suspicious, though not conclusive. It is noteworthy that all subsequent samples from this source gave excellent chemical results, but the bacterial pollution continued until the district was sewered.

In outbreaks of water-borne disease, the majority of attempts to isolate the actual pathogenic bacteria (*e.g.*, *Bact. typhosum*) from the water have been unsuccessful. This was in some measure due to technical difficulties, but with the introduction of other selective media (such as Szper's, Wilson and Blair's, etc.) greater success is now obtainable with typhoid and paratyphoid bacteria. The major problem, however, is that the water supply seldom comes under examination until a week or two after the specific contamination, which is usually

accidental or isolated rather than continuous, and the causative organisms have, by then, disappeared. The search for specific pathogens is made, therefore, only on comparatively rare occasions, and is not included in the routine examinations.

The routine bacteriological examination of water is concerned with the detection of more or less harmless bacteria, particularly those which are the normal inhabitants of the human and animal intestine. These "fæcal" bacteria are so abundantly present in the dejecta of man and animals that the pollution of water by exceedingly small traces of excrement can be demonstrated bacteriologically. Moreover, pathogenic bacteria, when present in sewage, are greatly outnumbered by normal organisms, such as *Bact. coli*, which can survive longer in water than the majority of the pathogens. It follows, therefore, that water which is free from *Bact. coli* should, in natural circumstances, also be free from disease-producing organisms. On the other hand, if small quantities of the water show the presence of fæcal bacteria, the possible presence of pathogens cannot be excluded, and the water must be regarded as unsafe. From the foregoing it is manifest that the presence in water of very few fæcal bacteria need not condemn the supply, but it should be viewed with suspicion, and measures taken to find and remove the cause of the contamination.

Apart from the routine detection of sewage or manurial pollution, bacteriology is also of great value in its application to water for the following purposes:—

1. To ascertain the effect of rainfall or drought on sources of water supply.
2. To ascertain the efficiency of a system of purification, such as storage, filtration, chlorination, etc.
3. To ascertain the cause of some change observed in a water, either at the source, or after passing through the distribution system of mains and reservoirs.
4. To ascertain the degree of pollution of river waters by the discharge of effluents from sewage works and factories. In such investigations, bacteriological examinations should be made of the effluents and of the river waters both above and below the outfalls.
5. To ascertain the efficacy of chlorination of sewage works effluents.
6. To ascertain the pollution by bathers of swimming pool water, and the efficiency of processes of purification.
7. To ascertain the degree of pollution of foreshore water by tidal outfalls from sewage works, or the purity of sea-water where oysters or other shell-fish are cultivated.
8. To ascertain, by examination of the bottled products, the cleanliness observed in the preparation of mineral or table waters.

The scope of the bacteriological examination varies according to the object for which it is performed. For general routine purposes, it includes the following:—

1. The determination of the total number of bacteria present in a

given volume of water which will grow on certain laboratory media (a) at blood heat, 37° C., and (b) at 20° C. to 22° C.

2. The detection, identification and approximate enumeration of the various organisms or groups of organisms which are predominantly excremental in origin. These groups, comprising the normal "fæcal bacteria," are (a) *Bact. coli*, (b) fæcal streptococci, and (c) *Cl. welchii*.

The value of bacteriological examinations of water is generally recognised, but great care is required in the collection of the samples, in conducting the examinations, and, above all, in the interpretation of the results. Want of experience, or a too rigid adherence to empirical standards, may easily lead to erroneous conclusions. Some knowledge of the history of a water is absolutely essential in order to enable correct inferences to be drawn. Also, it is necessary to know not only the source of the water, but the mode of collection of the sample, the period which has elapsed since it was taken, and the conditions under which it has been kept.

The estimation of the total number of bacteria is of less importance than was at one time believed. A high bacterial content is not unusual in some waters which are perfectly wholesome and remote from any pollution. Also, certain bacteria will multiply with great rapidity in some waters, such as the alkaline and organically pure waters derived from the Thanet Sand and Chalk under the London Clay. Many different species of bacteria are found in water and the majority are apparently quite harmless. A sample of water which is found to contain a large number of bacteria capable of growing at blood heat is not necessarily contaminated with matters of sewage or manurial origin. Such bacteria may be derived from quite harmless sources. The ratio of the number of bacteria growing at 20° C. to the number growing at 37° C. has been held to be important, but this is of comparatively little significance.

Of greater value are the detection and approximate enumeration of the fæcal bacteria, such as *Bact. coli*, which, though not necessarily harmful in themselves, are known to be of dangerous origin. The differentiation of such organisms has, however, to be conducted with great skill and care; and, in the case of *Bact. coli* particularly, considerable experience is required in the interpretation of the results. The definition of *Bact. coli*, and the methods employed for its detection, are often lax and inadequate, and an erroneous conclusion on this account is not infrequent.

A thorough training in bacteriology is essential before starting the work of the water bacteriologist, and even then problems arise from time to time which require for their elucidation the co-operation of a specialist. It will henceforth be assumed that no one will attempt the bacteriological examination of waters who has not previously acquired experience under a competent teacher. For this reason, it will be unnecessary to describe in detail the apparatus found in every bacteriological laboratory, or the various technical processes employed.

The Origin and Varieties of Bacteria found in Water

It is very seldom that any natural water is found to contain no bacteria, but some supplies obtained, for instance, from deep boreholes approach this condition. Bacteria are practically ubiquitous on the earth's surface, and the bacterial population of water depends on the extent and character of its contact with this surface.

In passing through the air as rain, snow, etc., water collects dust and bacteria according to the proximity or otherwise of dense populations and industries, and depending also on the climatic conditions. Rain, therefore, even before it touches the ground, is not sterile, except perhaps in remote and uninhabited parts of the globe. Numerous bacteria are added to water by contact with the soil, vegetation, life and matter of the earth's surface. The number and species of these bacteria differ widely. Thus, the bacteria in water collected on inhabited and agricultural areas which are fouled by sewage and manure will be vastly more numerous and varied than those in a water collected high up in the mountains. Many of the bacteria found in water are thus derived from the air, soil and vegetation. Some of these are able to multiply and continue their existence, whilst others die out. It is probably correct to speak, therefore, of natural water bacteria, for nowhere in this country can surface water be found which does not contain bacteria capable of persisting throughout very long periods of storage. These consist of cocci, sporing and non-sporing bacilli, spirilla and higher forms of microscopic fungi. A certain number of these bacteria cannot be cultivated under laboratory conditions whilst others require special conditions. Many species, however, grow with ease on ordinary laboratory media, especially at 20° C. or thereabouts, and some are also capable of developing at 37° C. and above. Many produce colonies of various colours such as yellow-brown, red, green and violet (the "chromogenic bacteria") and a large number liquefy gelatin ("proteolytic" bacteria). The aerobic spore-forming bacilli, *e.g.*, *B. subtilis*, *B. mycoides*, *B. megatherium*, etc., which flourish in the soil, are quite frequent in water, and large numbers occur in river waters, particularly in times of flood, when their colonies often smother the "agar plate cultures." The spores are very resistant to destruction and can withstand chlorination. Moreover, germination followed by multiplication can be demonstrated in waters which have been treated, *e.g.*, by chlorination, and thereafter stored. Such "after-growth" is often observed in practice, particularly in hot weather.

Certain members of the coliform group of bacteria, *e.g.*, the Intermediate and Aerogenes types, have their natural habitat in the soil and on vegetation and may therefore gain access to water without the latter necessarily receiving any manurial or sewage pollution. As would be expected they are frequently present in surface waters especially at times of flood.

Other varieties of bacteria which occur in the soil and may also make their appearance in water are the "nitrifying" and "denitri-

fyng" bacteria whose significance was discussed on p. 166 in connection with the nitrogen cycle.

The "sulphur bacteria" may similarly be found in water, and the higher forms (Thiobacteriales) were described on p. 139 *et seq.*, but a large number of true bacteria (Eubacteriales) also play a part in the "sulphur cycle," certain stages of which may take place in water. Of these lower forms, some of the ordinary saprophytes, *e.g.*, *Bact. pyocyaneum*, can effect a "non-specific" reduction of sulphur to sulphuretted hydrogen, whereas other changes in the cycle are "specific" and can be executed only by the specialised sulphur bacteria. The following diagram illustrates the part played by bacteria in the sulphur cycle :

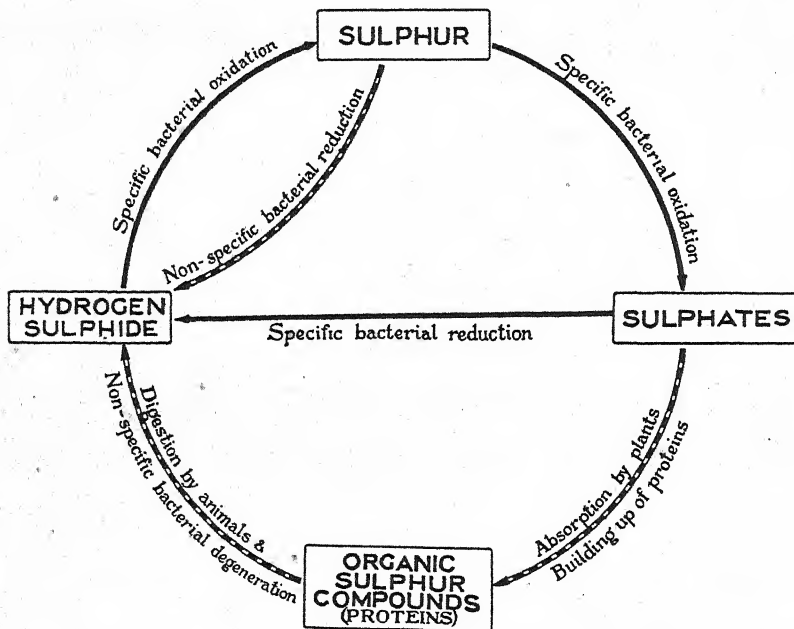


FIG. 24.

As in the nitrogen cycle, plants and animals also make their contribution to the sulphur cycle, but the activities of the sulphur bacteria proper are confined to the three reactions :

1. Oxidation of sulphuretted hydrogen—*e.g.*, *Beggiotoa*, *Thiothrix*.
2. Oxidation of sulphur—*e.g.*, *Thiobacilli*.
3. Reduction of sulphates—*e.g.*, *Bact. hydrosulphureum*.

Space does not permit a fuller description, and reference should be made to a Report by Bunker (1936) from which the above generalities and diagram are abstracted, and in which there is an excellent bibliography.

When present in water, sulphur bacteria may cause considerable economic troubles as both the oxidising and reducing types can produce deterioration or corrosion of concrete, stonework and metallic pipes.

The sulphate-reducing bacteria, however, are of particular concern to waterworks authorities as the presence of these organisms on filter beds may lead to an unpleasant odour of sulphuretted hydrogen in the water. These bacteria, also, when present in the water-seals of gasometers, have been responsible for contamination of the coal-gas by sulphuretted hydrogen.

The "natural" water bacteria are harmless and generally of no great significance. Little study has been given to them and no satisfactory classification made. They are of importance inasmuch as they may in some ways resemble, and must be differentiated from, bacteria derived from dangerous sources, or of pathogenic character. The soil bacteria, such as the chromogenic and aerobic-sporing bacilli, if present in sufficient numbers, point to the access of surface washings and are usually associated with waters of low grade organic purity, as may be derived from rivers or lakes. Only small numbers should be found in adequately protected deep well supplies. Mackenzie (1938) has recently emphasised the importance of certain of the fungi in the production of unpleasant tastes in river or reservoir-derived water supplies.

From the sanitary point of view, the most important and most objectionable bacteria that may be found in water are those obtained from sewage and manurial matter. Many of these are intestinal bacteria which are excreted in millions in the dejecta of man and animals. The majority are harmless, but disease-producing organisms may be present, and of the two sources, man is by far the more dangerous. These faecal bacteria are alien or unnatural to water and most of them gradually die out therein. They include *Bact. coli* and closely similar bacteria, enterococci (or "faecal streptococci"), staphylococci, and bacilli, *e.g.*, *Cl. welchii*, of the anaerobic spore-bearing group. In sewage there are many others in addition, and organisms associated with the anaerobes in processes of putrefaction are plentiful, *e.g.*, *Proteus* and the sulphide-producing bacteria.

The most important pathogenic bacteria, derived from human excreta, which may gain access to water are *Bact. typhosum*, *Bact. paratyphosum*, *Bact. dysenteriae* and *V. cholerae*. Bacteria of the *Salmonella* group, such as *Bact. aertrycke*, may similarly be added to water by the excreta of man and animals. Investigations (Ministry of Health 1938) into a milk-borne food-poisoning outbreak in 1936 showed that a healthy cow was repeatedly passing *Salmonella* (Dublin) in the faeces. Whether animals can act as faecal "carriers" of the enteric and dysentery organisms is still in doubt. Birds, *e.g.*, gulls, ducks and other water-fowl may, however, be responsible for the addition to water of many excretal bacteria (*Bact. coli*, etc.), and gulls particularly, on account of their unclean habits, may not be entirely innocent of the charge of adding typhoid bacteria to water.

Factors that Influence Bacteria in Water

The bacterial population of surface water is subject, therefore, to very wide variations, and in the same water it changes from day to

day. Some bacteria continue to live and multiply, others find conditions unsuitable and succumb, and there may be many new additions.

Filtration of the water downwards through the earth brings about the death or removal of many of the bacteria, and the reduction varies according to the character and depth of the filtering medium. Generally speaking, the deeper the water travels, the greater becomes its bacterial purity. Prominent exceptions occur in formations such as Chalk and Limestone which are characterised by fissures which may extend from the surface to great depths, and down which surface water may directly pass. The water-bearing capacity of the Chalk, and the movement of water therein, depend largely on fissures.

Waters obtained from strata, such as the Greensand, at considerable depths below the surface and reached by bore-tubes piercing an impervious layer, are usually of great bacterial purity and, in fact, practically sterile. The outcrop of the water-yielding stratum may be many miles distant, when filtration of the most prolonged and efficient character may have ensued.

It should never be taken for granted, however, that a well or bore-hole, even if extending below an impervious stratum, will necessarily yield, at all times, a bacterially pure water, and such supplies should be as carefully watched as others.

The bacterial purity of shallow wells is, on the whole, intermediate between that of strict surface waters and deep-well waters, and in this country it is seldom entirely satisfactory. Often, however, the bacterial improvement brought about by natural underground filtration, even of a few yards, is remarkable. There is, however, a grave danger that this efficiency may, at some time, break down; hence, shallow wells are generally looked upon with much suspicion and distrust as sources of water supply.

Springs yield waters of very varying bacterial character, and they are often subject to great and sudden change, brought about by rainfall. The popular idea that spring water is pure is fraught with danger. The water yielded by some springs, such as those supplying Portsmouth with over 10 million gallons a day, is really water which has percolated hundreds of feet downwards, and then been brought by geological circumstances to the surface again. In other cases, it is more or less surface water which has received little efficient filtration and purification. In this country, springs are not, on the whole, reliable sources of water, and with few exceptions the yields are inadequate for anything but small supplies.

The bacterial purity of water varies, therefore, according to the source, *i.e.*, whether river, spring, shallow well or deep well, and these differ greatly among themselves. Surface waters show the widest variations from the relative purity of the upland water or mountain lake to the gross impurity of some sewage-laden rivers.

Whilst the amount and remoteness of sewage and manurial pollution are the most important sanitary considerations with regard to the bacterial content of water, there are other factors to be mentioned.

The general factors that influence bacteria operate more or less similarly in water, and the main tendency is towards purification, especially as regards intestinal bacteria for which water is an unfavourable environment.

The density of a bacterial population in water depends in large measure on the quantity and quality of food available. The nutritional requirements of bacteria are, however, often very simple, and, as previously mentioned, organically pure deep well waters can support comparatively large numbers of bacteria, and, for a time, permit rapid multiplication. Under certain conditions, bacteria may live for long periods even in distilled water, and, if the reaction is suitable, temporary multiplication can be demonstrated.

The nature, as well as the quantity, of the organic matter present in water has some bearing on bacterial multiplication, and also on the species of bacteria that develop.

The inorganic constituents of the water also exert an influence, in some cases favourable, in others inhibitory. Some of the soil bacteria require the simplest form of nutrition, and the inorganic salts of water may be utilised as a source of energy. High concentrations of some inorganic salts may retard bacterial multiplication, whilst low concentrations of the same salts may stimulate growth.

Metals are often inhibitory to growth, and copper, even in the most minute trace, is very detrimental to bacteria in water. Silver and aluminium have a similar effect. Iron and manganese, in relatively large amount, inhibit the growth of certain bacteria, but encourage the development of others, such as the so-called "iron-bacteria."

The gaseous constituents of water are also of some importance. Oxygen is favourable to some bacteria, but not to others, and carbonic acid gas appears to have a similar effect. Sulphuretted hydrogen is often found in water and is associated with growths of "sulphur bacteria." In large, deep, impounding reservoirs, the species of bacteria found in surface samples are quite different, therefore, from those obtained at the bottom where conditions of darkness and anaerobiosis prevail.

The reaction of the water is a factor of some importance to bacteria, and few can tolerate any degree of acidity or caustic alkalinity. The limiting range usually runs from pH 4 to pH 9, and there is for most bacteria an optimum pH. This for *Bact. coli* is pH 6 to pH 7, and in artificial media growth will not continue at pH 4 or over pH 9. Acidity and alkalinity are both inhibitory and destructive to bacteria, and the latter operates in the excess lime treatment of water when the pH is raised to 10-12. A period of about six hours at this pH is sufficient to destroy all *Bact. coli* and most other bacteria in water. Spore-bearing bacilli, both aerobes and anaerobes, are more resistant to acidity and alkalinity.

It is probably due partly to the acidity that some natural surface waters contain relatively few bacteria. In certain industrial areas, rain water may take up appreciable traces of acids, such as sulphuric acid,

from the atmosphere, and the discharge of trade-wastes to water courses may render the waters distinctly acid. Moorland, upland, and marsh-land waters are often acid owing to the presence of organic acids derived from peat and other vegetable matter. Natural waters may, therefore, have a pH value of under 5, and this point must be considered in the interpretation of the results of the bacteriological examinations.

Water is never found in this country with pH over 9, except when it has been in contact with recent cement work or been treated with lime. The alkaline sodium carbonate waters yielded by the Thanet Sand and certain other geological formations have a pH of approximately 8.5, and these waters are favourable to both bacterial and algal growths.

The production of acids and other substances by the bacteria themselves is responsible for the arrest of multiplication in artificial cultures, and it is probable that this action occurs also in water.

Bacteriophage, symbiosis and antagonism doubtless operate also and play a material part in the varying bacterial flora which is particularly observed in river and reservoir waters. Growth of one organism may make conditions favourable for the multiplication of others, *e.g.*, by the depletion of oxygen, the production of sulphuretted hydrogen, the breaking down of organic matter, or other means. On the other hand, the competition for food or the production of toxic bodies by one class of bacteria may lead to the elimination of others.

Microscopical examination will often show collections of millions of bacteria in close contact with certain forms of active living algæ. It appears that certain bacteria find favourable conditions in that environment. On the other hand certain algæ and protozoa are detrimental to some bacteria. These forms of life play some part in the bacterial purification of surface water, and German workers have asserted that the death of pathogenic bacteria, such as typhoid bacteria, in water containing many protozoa is very rapid owing to the activities of the latter. It would be very unwise, however, to rely on protozoal activity, and we have not observed any evidence of such action by protozoa in experiments carried out with *Bact. coli* as the test organism. It is probable that some protozoa ingest and destroy bacteria, whilst many are quite inactive in this respect, and, in general, we regard this as a comparatively minor factor in the self-purification of water.

Seasonal changes have a marked and complex influence on the bacteria present in surface waters. The first effect on rivers and lakes of heavy rainfall after a dry period is the addition to the water of many bacteria, whilst a continuation of the rainfall often leads to the reverse effect. Many wells and springs yield bacterially pure water in normal periods, but marked deterioration occurs after heavy rainfall. Supplies derived from the Chalk and Limestone are particularly liable to be affected in this manner.

The bacterial condition, both as regards total bacteria and intestinal organisms, of the rivers and other supplies of this country is generally worst in the winter months, and rainfall and snow are the

most important factors in this regard. The comparative absence of sunlight, and the lower temperature, causing a subdued activity of protozoal and algal life, and a slower rate of flocculation and sedimentation, assist in bringing about this result.

Temperature has a marked influence on bacteria, and each species has its optimum temperature for multiplication. The generation time of *Bact. coli*, in broth, was shown by J. E. Lane-Claypon (1909) to be 0.32 hours at 42° C. and 1.3 hours at 20° C.

Water bacteria multiply at the warmer temperature of the summer months, and the increase may be very appreciable in twenty-four hours.

Freezing does not kill bacteria, but it inhibits their activities.

Houston has shown that the survival of typhoid bacteria in raw river water is much favoured by low temperatures, and the higher the temperature up to 37° C., the quicker was the death-rate of *Bact. typhosum* (see Chap. XXXIII). No doubt the greater activity of other bacteria at the higher temperatures was instrumental in bringing about this result.

It has for long been known that the waters of some rivers are relatively lethal to certain intestinal bacteria. The destruction of the bacteria in such cases is more rapid than can be explained by the usual or better known processes of self-purification. An explanation of this bactericidal property of river waters has been put forward in the Twort-d'Herelle phenomenon (bacteriophage). Twort, in 1915, noted a peculiar bacterial change in which, by a process of autolysis, micrococci disrupted and granular *débris* remained. d'Herelle, in 1917, recorded similar findings with dysentery bacteria. The process is observed by the eating away and clearing of colonies on solid media, or by the disappearance of the turbidity of a bacterial growth in broth. Swelling of the bacterial cell precedes its disintegration. The nature and origin of the lytic agents are not fully understood, but they are transmissible and appear to act only on living active organisms at certain phases of growth. Lytic filtrates can be obtained from cultures of intestinal organisms, from intestinal extracts, and from sewage.

The possession of properties lytic to certain intestinal organisms has been ascribed to the waters of various rivers of India, France and elsewhere, and this would be expected from the findings of Caldwell (1927) regarding sewage effluents.

It would seem probable that the process described by Twort plays some part in the self-purification of sewage and manurially-polluted water. This may also explain the great diversity of findings regarding the time of survival of intestinal organisms in water, and account in part for the more rapid destruction of pathogenic organisms in an impure water than in a pure one.

It is impossible to assign the exact importance of each factor in the self-purification of water, for there are a large number of influences operating simultaneously, and the respective degrees of importance differ under varying conditions. The bactericidal power of sunlight may, for example, be appreciable in clear water in some parts of the

world, but sunlight plays a relatively unimportant part in this country, and it is ineffective in turbid water.

Storage is one of the most important methods of self-purification of water. It acts naturally in lakes and rivers, and is brought about artificially by many water authorities. During storage the various factors already mentioned each play a part, but the process of sedimentation is added as a potent factor in the bacterial purification of water.

References

- BUNKER. 1936. Chemistry Research, Special Report No. 3. "A Review of the Physiology and Biochemistry of the Sulphur Bacteria." H.M. Stationery Office, London.
- CALDWELL. 1927. *Journal of Infectious Diseases*, XL., 575.
- LANE-CLAYTON. 1909. Quoted from M.R.C., System of Bacteriology, Vol. I, 1929.
- MACKENZIE. 1938. 33rd Annual Report to M.W.B.
- MINISTRY OF HEALTH. 1938. Reports on Pub. Health and Med. Sub., No. 82. H.M. Stationery Office, London.

CHAPTER XXVII

DETERMINATION OF THE NUMBER OF BACTERIA IN WATER

"Total Counts"

It should be clearly understood that all the bacteria present in a sample of water are not revealed by the methods to be described, but only a fraction of them, namely those which, on certain solid media and under certain laboratory conditions, will develop into visible colonies.

It is now standard practice to use nutrient agar as the culture medium and to incubate one series of "plates" at 37° C. (*i.e.*, blood heat) and another series at 20° C. to 22° C. These represent the so-called "hot counts" and "cold counts" respectively.

Nutrient gelatin was formerly employed as the medium for the cold counts, as the proportion of proteolytic bacteria could thereby be demonstrated, and this was at one time considered to be of some value. The presence of these bacteria in water is, however, of no greater importance than that of other "water bacteria," and, as parallel experiments made by us on hundreds of waters have shown that the numbers of colonies developing at 20° C. on agar and on gelatin respectively are not significantly different, we have for several years advocated the use of agar throughout. In this way, unnecessary duplication of media and the disadvantages associated with gelatin are avoided, for, apart from the intricacies of preparation, and the low melting point (about 24° C.) which introduces difficulties in hot weather, there is always the danger that the proteolytic bacteria may totally liquefy the medium before the prescribed period of incubation is completed and thereby render enumeration impossible.

The number of bacteria found to develop into visible colonies on the agar medium after certain periods of incubation is expressed in terms of 1 c.c. of water. Some water bacteria are unable to multiply on agar either at 37° C. or at 20° C., whilst others develop so slowly that colonies become visible only after prolonged periods of incubation. Experience shows that, up to a point, progressively longer incubation results in the appearance of more and more colonies. It is necessary, therefore, to fix a time limit for incubation, and we recommend one day as the most suitable period for the cultures at 37° C. and three days for those at 20° C. In Report No. 71 of the Ministry of Health (1939) it is suggested that the 37° C. cultures should be counted after two days, but we find it advantageous to continue the former procedure of making the enumerations after incubation for one day. To conform, however, with the recommendation of Report No. 71, we include an additional series of cultures for two days' incubation at 37° C.

The value of the mere enumeration of bacteria in water is relatively small, but it will manifestly be less if no standard method is adopted. The need for a reasonable degree of uniformity in media, technique, etc., is properly emphasised in Report No. 71, and it is a well-known fact that, besides variations in procedure, alterations in the composition, method of preparation, and reaction of the medium employed, will largely influence the number of colonies which develop from a known quantity of the water under examination. The medium must therefore also be standardised, and any results we express are based on the use of media prepared according to the formulæ given in the Appendix of this volume. It cannot be taken for granted that results obtained by other methods are comparable or admit of similar interpretation.

The method of collecting a sample of water for bacteriological examination is described in Chapter XV, but the necessity for the most scrupulous care in collection is again emphasised.

The interval of time which elapses between the collection of the sample and the commencement of its examination is also a matter of importance. The longer this period, the less true are the results likely to be, and the changes in a bottled sample may indeed be extensive. A period of twenty-four to forty-eight hours may result in an enormous increase of bacteria in some waters, whilst others under the same conditions show comparatively little change. Multiplication does not depend solely upon the organic content of the water, and we have repeatedly found that certain borehole waters of great organic purity, especially the alkaline or sodium bicarbonate waters, are very favourable to rapid bacterial multiplication, whilst other borehole waters of similar organic purity, but with different saline constituents, show comparatively little bacterial change when kept for similar periods under the same conditions. The chemical composition of the water and its reaction appear to be of decisive importance in this respect.

A potent factor in the multiplication of bacteria in samples of water is temperature, and the lower this can be kept, the less likely is multiplication to take place. Whipple (1901) examined thirteen samples of water from sources not defined and kept them at temperatures ranging from 2.4° C. to 23.6° C. He found in all a slight decrease in the number of bacteria in six hours, a marked increase in twenty-four hours and an enormous increase in forty-eight hours. This is not, however, in our experience, invariably the case. Much depends on the origin and character of the water, the species of bacteria originally present, and other factors, some of which are still obscure. When stored in bottles in an ice-box at about 5° C. for twenty-four hours, most waters show insignificant bacterial changes.

The ideal method would be to make platings immediately on collection of the sample, but, since this is seldom practicable, the following rules should be observed. These have given very satisfactory results in our practice.

Samples of water for bacteriological examination should be collected in small, sterilised glass bottles with protected glass stoppers (see

p. 189), and the bottles should be filled. These should at once be packed for transit in an ice-box and the examination should take place with the least possible delay. The time between collection and examination should, preferably, not exceed twelve hours. More time than this is seldom required in this country, and, in the majority of cases, the interval can be reduced to six hours or less, which is desirable, particularly in the case of organically and bacterially impure waters.

Of the samples arriving at our laboratories under these conditions we have records of thousands which were of natural waters known to be originally pure and which showed on examination bacterial counts of less than 10 per c.c.

For practical purposes, multiplication is *nil* or negligible in such circumstances, and, when it does occur, the most important bacteria from the sanitary point of view, *i.e.*, the intestinal organisms such as *Bact. coli*, are not affected. We have, however, found that other closely-allied lactose-fermenting bacteria, particularly the *Bact. aerogenes* subgroup, are capable of temporary multiplication in certain suitable waters, such as the alkaline sodium carbonate waters and waters containing some species of water-weeds and algæ. The bacterial changes occurring in grossly polluted waters, sewages, etc., are very rapid and complex, and examinations conducted at intervals of only a few hours will show wide quantitative and qualitative differences. Due consideration to these various points must be given in the interpretation of the results of the bacterial enumerations in any sample of water.

Variations in the bacterial counts, besides those due to the above causes, may occur in samples from the same bottle, as the bacteria tend to adhere together in masses or be collected in particles of suspended matter. To minimise this difficulty, the sample should be well shaken immediately prior to the commencement of the examination, though the most vigorous shaking will not always completely separate the bacteria.

The greater the number of plates made, the more accurate will be the final counts, but, if the source and history of the water under examination are known, the number of plates required for each examination can be minimised. Thus, a pair of plates for incubation at each of the two temperatures may suffice, with an additional pair if hot counts are to be made after both one and two days' incubation.

Apparatus Required (for Details, see Appendix). Nutrient agar, contained and sterilised in 10 c.c. quantities in plugged tubes.

Sterilised Petri dishes of 10 cm. diameter.

"Dilution bottles," each containing 90 c.c. of sterile, distilled water.

Sterilised 1 c.c. and 10 c.c. pipettes.

Procedure. Prior to use, the tubes of agar are placed in boiling water (until the medium is completely melted) and are then cooled to 40° C. (at which temperature the medium still remains in the liquid state).

The quantities of water taken vary according to the anticipated bacterial purity of the water. Where the water is expected to be

unpolluted, 1 c.c. is introduced by sterile pipette into each of four (or six) Petri dishes. Where the quality of the water is less certain, decimal dilutions are prepared by adding 10 c.c. of the sample to the 90 c.c. distilled water in a dilution bottle, and so on, using a fresh sterilised pipette for each dilution and ensuring thorough mixing. From the appropriate dilutions, 1 c.c. quantities corresponding to 0.1 c.c., 0.01 c.c.,

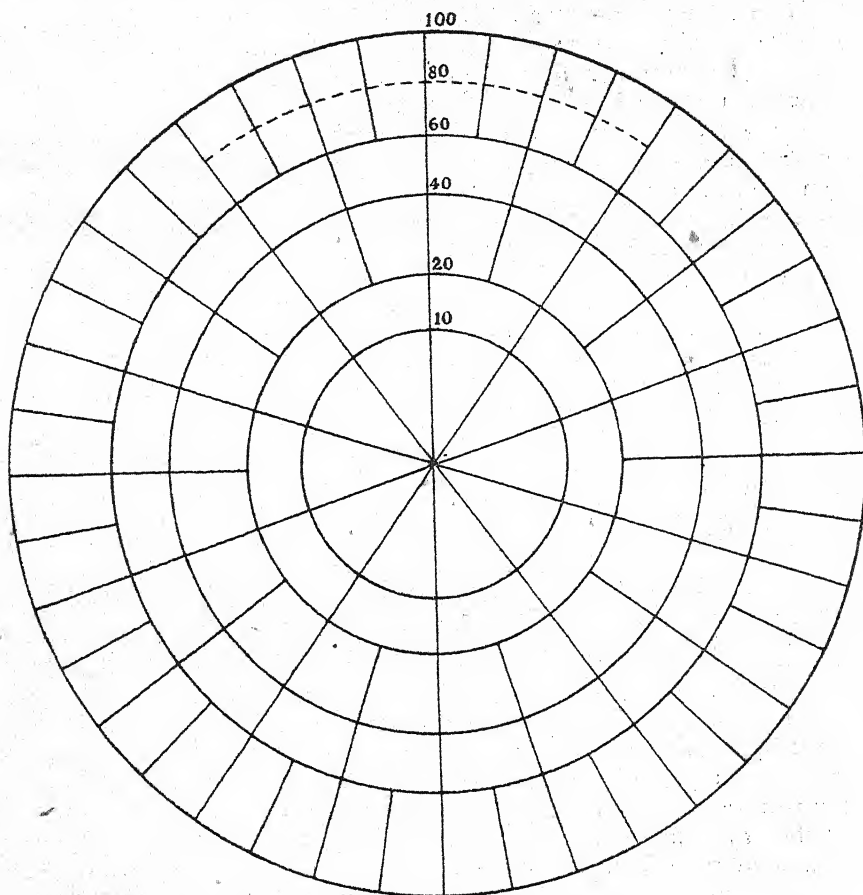


FIG. 25. Counting Disc.

etc., of the original water are transferred to the required number of Petri dishes (four or six for each dilution). With waters the quality of which is unknown, a fairly large number of dilutions (with consequent multiplicity of plates) may be required, but experience enables these to be reduced to practical limits. The object in all cases is to provide a suitable pair of plates for each of the 37° C. and 20° C. enumerations.

Into each of the "inoculated" Petri dishes is poured the content

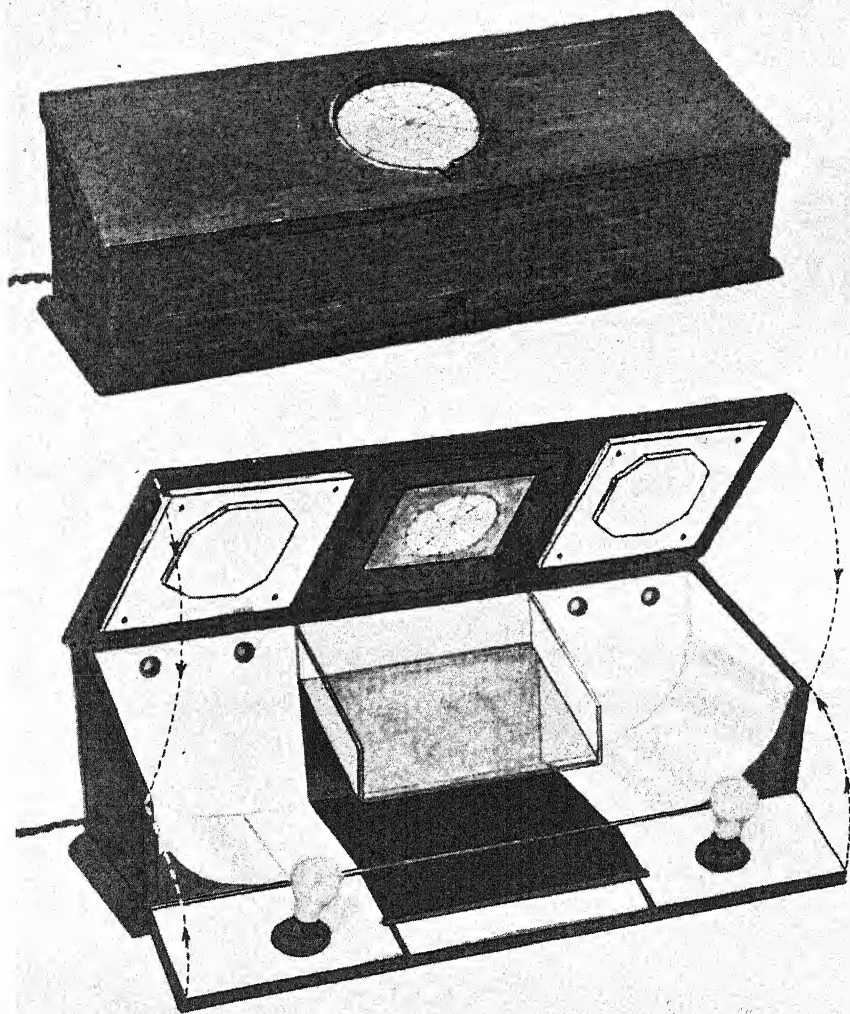


FIG. 26.—Counting Chamber.



of one of the cooled agar tubes, the cover being raised as little as possible and immediately replaced. Admixture is secured in the process of pouring and also by a series of careful rotatory and to-and-fro movements of the plate. The risk of spilling the medium over the edge of the plate (and thereby vitiating the examination) is reduced if, throughout the mixing process, the plate is kept flat on the bench. The plates are left on the bench until the medium is solidified. They are then transferred to their respective incubators, in which they are kept in the inverted position for one, two and three days, as required.

When removed from the incubators for counting, the plates are placed on a segmented disc (see Fig. 25), preferably incorporated in a "counting chamber" (see Fig. 26), and the counting of the colonies is performed with the aid of a lens of focal length $1\frac{1}{2}$ inches.

The main object of the enumeration is to ascertain whether the number is large or small, and no attempt at great accuracy on any particular sample is made or is worth while. The elaborate experiments and calculations of statisticians regarding the strict accuracy or otherwise of bacterial counts are of little concern in the practical work of the water bacteriologist. With very pure waters giving zero counts on 1 c.c. platings, some workers prefer to plate out 2 c.c. or even 5 c.c., but this also is seldom worth while since a count of less than 1 per c.c. gives all the information required.

The best plates to count are those with under 300 colonies, and in such cases all the colonies may be counted. Where dilutions have been prepared, the plates giving counts between 30 and 300 should be selected and the others discarded. In those cases where, through lack of adequate dilutions, the plate counts all exceed 300, a reasonably fair approximation can be obtained by counting the colonies in a few of the sectors and calculating the total.

Notes concerning the colonies are sometimes valuable, such as the presence and number of chromogenic colonies, and the presence of the dendritic and spreading growths of *B. mycoides* and similar aerobic spore-bearing soil bacteria. The latter not infrequently cover the whole surface of the plate and vitiate the results, but one of the several advantages of duplicate plates is that both plates are seldom equally affected. The spreading growths are often obtained from river waters after heavy rainfall, from well waters contaminated by surface washings, and are frequently noticeable in chlorinated water, particularly after storage.

The "Coliform" Count

Another medium is often used to obtain a bacterial count of a different kind. This is neutral-red bile-salt lactose agar ("MacConkey Agar," see Appendix), the platings of which are made as before and incubated at 37° C. for one day. Only the red colonies which develop are counted. A count is thus obtained of the bacteria capable of growing in the presence of bile-salt and able to produce acid from lactose. The majority of water bacteria are devoid of these powers

which are essentially possessed by the coliform group of bacteria, and the count is, therefore, useful in association with examinations for *Bact. coli*. No red colonies are found on 1 c.c. platings from pure waters, but the greater the degree of sewage pollution, the higher is the number of red colonies. The number is always less than the agar counts.

Bile-salt lactose agar counts are useful in the comparison of one sample of water with another, especially when dealing with impure waters, and in providing a rough estimate of the probable number of *Bact. coli* present. All the red colonies are not, of course, *Bact. coli* or even coliform bacteria.

These "Coliform" or "N.R.A." (neutral-red agar) counts, when made on samples of river water collected above and below various points of pollution, such as sewage works outfalls, often clearly demonstrate the degree of pollution by the several discharges.

TABLE I

SHOWING EFFECT ON THE "COLIFORM COUNT" ON NEUTRAL-RED BILE-SALT LACTOSE AGAR OF VARIOUS POINTS OF SEWAGE POLLUTION ON A RIVER WATER

"Coliform Count" on Neutral-red Bile-salt Lactose Agar per 1 c.c.

	Above Point of Pollution.	Sewage Discharge.	Below Point of Pollution.
1 . .	90	3,500	260
2 . .	30	28,000	70
3 . .	24	60,000	900
4 . .	60	900	70
5 . .	6	1,600	74
6 . .	8	13,000	126
7 . .	84	3,300	126
8 . .	78	7,200	280
9 . .	48	1,600	190
10 . .	32	1,200	220
11 . .	180	2,100	250
12 . .	480	14,400	4,400
13 . .	380	480	390
14 . .	22	100,000	22,000
15 . .	260	—	2,100
16 . .	600	—	1,700
17 . .	4	15,600	260
18 . .	40	—	98
19 . .	8	—	2,300
20 . .	50	—	88
21 . .	7	—	520
22 . .	10	—	52
23 . .	40	—	940

Such counts are also very useful in experimental work regarding the efficacy of methods of sterilisation. Since this medium is often used for cultivating the typhoid-paratyphoid bacteria, extensive experience of its use is helpful, as the appearances of the colonies of

innocent bacteria become familiar, and this facilitates the search for the pathogenic types.

The colonies of enterococci (*i.e.*, the "faecal streptococci") and other bile-tolerant streptococci are distinctive on this medium as small, round, discrete, deep-red points.

Bact. pyocyaneum grows as a "dirty, smoky, brownish-green colony or confluent growth, and is readily recognised by the experienced worker.

Bact. aerogenes can often be readily distinguished from *Bact. coli*. The latter typically presents a discrete, circular, reddish colony of average diameter of 2 to 3 mm. with a darker red centre gradually shading off into a transparent, pink periphery, whereas the *aerogenes* group usually produce a mucoid and often confluent growth which is pale pink in the central parts and translucent white at the edges. The appearances vary considerably with the different forms of bile-salt used in the preparation of the medium. With commercial bile-salt, *Bact. coli* causes a purplish haze to appear in the medium surrounding the colony. Some authorities consider this to be an advantage, but we prefer to avoid this phenomenon by using sodium taurocholate as the actual colony appearances are more easily recognisable. All gradations between the two extremes described above may be encountered, and the "Intermediate" groups (see later) can so closely simulate *Bact. coli* that further tests are required for the final differentiation. Generally, however, we find platings on this medium to be of great help and we recommend its use when polluted waters are under examination.

The "Coliform Count" on neutral-red bile-salt lactose agar corresponds closely with the "probable number" of "presumptive coliform bacteria" (see later) as indicated by the production of acid and gas in lactose bile-salt broth, and a series of results is shown in the following table:—

TABLE II

RELATION OF THE "COLIFORM" COUNT ON NEUTRAL-RED BILE-SALT LACTOSE AGAR TO THE "PROBABLE NUMBER" OF "PRESUMPTIVE COLIFORM BACTERIA" INDICATED BY THE REACTIONS IN MCCONKEY'S LIQUID MEDIUM.

	Coliform Count per c.c.	Presumptive Coliform Bacteria.				
		Present in ... c.c.	Absent from ... c.c.	Probable number per c.c.		
				Minimum.	Maximum.	Average.
River Waters .	3	5.0	1.0	0	0	0
River 1.	0	1.0	0.5	1	1	1
	5					
	17					
	2					
	3	0.5	0.1	2	9	6
	4					
	5					
	6					
	7					
	26					

	Coliform count per c.c.	Presumptive Coliform Bacteria.				
		Present in ... c.c.	Absent from ... c.c.	Probable Number per c.c.		
				Minimum.	Maximum.	Average.
<i>River Waters . River 1—contd.</i>	14	0.1	0.01	10	99	50
	18					
	21					
	26					
	26					
	27					
	36					
	80					
	98	0.01	0.001	100	999	500
<i>River 2.</i>	0	10.0	1.0	0	0	0
	4	1.0	0.1	1	9	5
	8	0.1	0.01	10	99	50
	11					
	19					
	24					
	30					
	60					
	70					
	88					
	90					
	400					
	110	0.01	0.001	100	999	500
	180					
	190					
	230					
	260					
	480					
	900	0.001	0.0001	1,000	9,999	5,000
	1,300					
<i>Sewage Effluents.</i>	400	0.01	0.001	100	999	500
	410	0.001	0.0001	1,000	9,999	5,000
	900					
	1,500					
	1,600					
	3,000					
	4,000					
	7,000	0.0001	0.00001	10,000	99,999	50,000
	8,000					
	16,000					
	27,000					
	28,000					
	28,000					
	34,000					
	60,000	0.00001	0.000001	100,000	999,999	500,000
	67,000					
	13,000					
	120,000					
	160,000					
	400,000					

The Value of Plate Counts in Assessing the Efficiency of Treatment Processes

The enumeration of the bacteria present in a water is of great value when the object is to ascertain the effect of filtration, but to determine the efficiency of a filtration system something more than an occasional bacteriological examination is required. The arrangements for filtering should be inspected. Almost any kind of filter may on occasions yield a satisfactorily filtered water, but what is, or should be, required to be known is whether the apparatus or arrangement can be trusted to give a uniformly good water under all ordinary circumstances. Installations which at first give practically sterile water may be found after a time to yield a filtrate containing more organisms than the unfiltered water. Such an increase is often found in the filtrates passed when units have just been returned to service after cleansing. As previously stated, no system can be considered satisfactory unless it is sufficiently large to filter considerably more than the amount daily required, thus admitting of one or more filters being thrown out of use for cleansing and repairing. Each filter of a battery should be complete in itself and be separately connected with the common filtered water channel or reservoir, so that samples of water can be obtained from each filter, and at any time a unit can be cut out of the system and the water directed into another channel. There should also be an arrangement for regulating the rate of filtration.

When slow sand filters are properly constructed and worked at a slow rate, *i.e.*, not more than one million gallons per acre per day, there is little difficulty in producing a water which will uniformly contain less than 100 micro-organisms per cubic centimetre capable of growing upon nutrient agar (or gelatin) at 20° C. in three days. The standard originally suggested by Koch was 100 bacteria per cubic centimetre growing in two days, but the above is the standard now frequently adopted. Of course, it is understood that the sample examined is taken direct from the filter and not after chlorination, or storage of the water in a service reservoir.

Operation of slow sand filters at more rapid rates leads to inferior bacterial purification, and Table III shows the results obtained at a works where it became necessary to filter at a rate exceeding 3,000,000 gallons per acre per day.

The table is interesting in showing also the result of prechlorination which was instituted owing to the need arising for an increased rate of filtration and the inadequate bacterial removal that resulted therefrom.

Filtration works which uniformly produce a water containing less than 100 bacteria per cubic centimetre, capable of growing upon agar in three days, may, if otherwise satisfactory, be considered efficient. This statement refers to samples of water collected at the filter beds. If sampled after the water has traversed a long length of main, or after it has passed through a service reservoir, even the most efficiently filtered water may give much higher results, especially in summer and

TABLE III

SHOWING EFFECT OF SLOW SAND FILTRATION AT A RATE EXCEEDING
3,000,000 GALLONS PER ACRE PER DAY

	Treatment by Sand Filtration.		Treatment by Pre-chlorination and Sand Filtration.	
	Raw.	Treated.	Raw.	Treated.
Average agar count, 1 c.c., 1 day at 37° C.	104	14	39	4
Average gelatin count, 1 c.c., 3 days at 20° C.	705	153	883	21
Percentage of samples containing Bact. coli in—				
100 c.c. or less	100	40	100	0
10 c.c. or less	92	2	96	—
1 c.c. or less	42	0	19	—
0.1 c.c.	4	—	3	—
Percentage of samples giving the Cl. welchii reaction in 100 c.c. .	74	10	24	3
No. of samples	50	50	78	78

autumn. This important point is often overlooked. A larger number of bacteria found in a tap water does not necessarily indicate that an imperfectly filtered water is being supplied from the works. It should also be noted that even when filtered water is chlorinated at the waterworks, taps on the mains may, owing to "aftergrowth" or other causes, yield a water with high bacterial counts.

Occasionally the best managed works may send out a water containing a large number of bacteria, but as soon as this is detected the individual filter beds should be examined to discover which are at fault. The average standard obtainable at well managed works may be gathered from a study of the annual and other reports of the Director of Water Examination, Metropolitan Water Board. The following figures are taken from various tables in the Report for the year ending March 31, 1923 :—

Table IV shows :—

1. The difference in character of the three rivers from which the raw water is derived.
2. The effect of season and rainfall upon each stream.
3. The character of the water from each after storage and filtration.
4. That, generally speaking, the best raw water yields the best filtered water, and the worst raw water the worst filtered water.
5. The high standard of excellence maintained notwithstanding the extreme variation in the number of bacteria in the raw waters.

All the results quoted in Table IV were taken on the third day, so the counts were presumably made sixty to seventy-two hours after

TABLE IV
AVERAGE NUMBER OF MICROBES PER CUBIC CENTIMETRE GROWING ON
GELATIN AT 20-22° C. COUNTED ON THE THIRD DAY

Date.	Rainfall.		Raw Waters.			Filtered Waters. ¹		
	Thames Valley.	Lee Valley.	Thames Water.	Lee Water.	New River Water.	Thames Water.	Lee Water.	New River Water.
Total 1921-22	19.96	17.66	—	—	—	—	—	—
Averages, 1921-22	—	—	1,544	3,257	1,224	18.7	43.0	16.3
April, 1922 . . .	3.27	2.82	2,423	2,670	633	16.5	49.2	26.7
May	1.10	1.15	779	2,304	838	17.4	65.5	21.5
June	1.28	1.28	589	1,246	575	25.8	47.5	22.2
July	4.49	3.65	1,000	2,176	1,427	16.4	59.1	25.9
August	3.91	2.44	1,662	2,095	1,454	15.2	53.1	16.0
September . . .	1.93	2.73	800	1,552	1,094	15.5	57.6	12.1
October	0.94	0.72	560	1,058	706	12.0	53.7	13.7
November	1.59	1.20	1,532	1,643	1,129	14.0	46.7	13.1
December	3.48	2.45	3,340	3,522	1,337	12.3	47.1	9.1
January, 1923 . .	1.72	1.32	7,232	8,686	5,123	21.2	49.2	25.0
February	4.49	3.18	8,245	11,521	4,330	16.8	47.8	17.9
March	2.48	1.91	5,767	7,266	3,055	12.9	48.7	16.5
Total, 1922-1923 .	30.68	24.85	—	—	—	—	—	—
Averages, 1922-23	—	—	2,774	3,732	1,815	16.4	52.3	17.9

¹ The samples are all collected as the water leaves the filter beds, and not taken from the water-mains in the districts supplied.

plating. These figures consequently cannot be compared with counts made on the fourth day or later, and it is not uncommon to see such counts recorded. It is important to remember this, as many waters contain slowly growing microbes, the colonies of which are not visible on the third day. The visible colonies may, for example, number only thirty or so on the third day of incubation yet be innumerable by the sixth day. The bacteria capable of growing on agar at 37° C. within twenty to twenty-four hours vary to a smaller extent than those growing at 20° C. to 22° C. in three days. The growth at the end of two days at 37° C. may, however, far exceed the growth at the end of one day, hence when comparing results it is absolutely necessary that the period and temperature of incubation should be the same. *Neither the 37° C. nor the 20° C. count pretends to represent the total number of bacteria present, but merely the number capable of producing visible colonies on the particular medium within the given time.*

Table V is taken from the same report as Table IV. A study of these tables shows :—

1. That the variation in the number of microbes growing at 37° C. is not nearly so great in the raw waters as is the variation in the number of those growing at 22° C.

2. That in the raw waters the ratio of gelatin colonies to agar colonies is highest when the raw water is at its worst, judged by the gelatin count; and lowest when the raw water is at its best, judged by the same standard.

3. That in the filtered waters the ratio is so variable as to afford no index of the quality of the water.

The Lee water, when filtered, was the worst of the waters supplied, the Thames water the best, and the New River water intermediate. In the three cases the ratios of the gelatin to the agar counts are as under :—

New River	17.9 : 3.4	approximately	5 : 1
Thames	16.4 : 2.0	„	8 : 1
Lee	52.8 : 11.5	„	5 : 1

TABLE V

NUMBER OF MICROBES PER CUBIC CENTIMETRE CAPABLE OF GROWING ON AGAR AT 37° C. IN TWENTY TO TWENTY-FOUR HOURS

Date.	Raw Waters.			Filtered Waters.		
	Thames Water.	Lee Water.	New River Water.	Thames Water.	Lee Water.	New River Water.
Average for 1921-22	94	193	59	2.9	12.7	3.2
April	119	116	40	1.5	10.1	5.2
May	87	157	63	1.8	12.9	2.6
June	85	124	60	6.2	20.0	3.3
July	111	134	107	1.5	10.5	2.6
August	137	164	126	2.1	12.7	1.6
September	105	127	90	2.8	19.3	3.5
October	65	56	35	1.2	5.1	1.4
November	136	40	28	1.2	8.8	1.1
December	224	191	57	0.6	7.8	0.9
January, 1923	390	217	148	1.9	10.1	8.2
February	536	365	223	1.2	8.5	5.4
March	269	155	97	2.0	13.9	5.7
Average for 1922-23	201	155	95	2.0	11.5	3.4

It has been asserted that in pure waters the ratio should not be less than 10 : 1, and waters have been condemned on this account. As a matter of fact, the ratio is of no value save for comparing the same water at different times and under different circumstances. In Table VI are a few determinations made in our laboratories and taken at random from our records. The variations in the ratios are so wide, considered either in relation to waters from different sources or to waters from the same source at different times, that it is difficult to draw any conclusions from them. Waters from some sources appear to contain very few bacteria capable of growing on agar at 37° C. compared with those growing on gelatin at 20° C. ; in others the agar count is relatively

TABLE VI

NUMBER OF MICROBES PER CUBIC CENTIMETRE CAPABLE OF GROWING ON AGAR AT 37° C. IN 1 DAY AND ON GELATIN AT 20° C. IN 3 DAYS, AND RATIOS

Source of Water.	Colonies per c.c.		Ratio Gelatin to Agar.
	Gelatin.	Agar.	
Unpolluted deep well in chalk .	61	3	20 : 1
" " " " .	23	3	7 : 1
" " " " .	161	13	12 : 1
" " " " .	42	7	7 : 1
" " " " .	83	14	6 : 1
" " " " .	9	3	3 : 1
" " " " in sandstone .	14	2	7 : 1
Unpolluted spring water .	17	2	8 : 1
" " " " .	34	6	6 : 1
" " " " .	51	3	17 : 1
Polluted river water .	2,900	170	17 : 1
" " " " .	7,960	510	15.5 : 1
" " " " .	6,300	140	45 : 1
" " " " .	29,600	3,300	9 : 1
" " " " .	14,700	920	16 : 1
Polluted deep well in chalk .	260	72	3.5 : 1
" " " " .	84	4	21 : 1
" " " " .	61	7	8.7 : 1
" " " " .	440	30	15 : 1
" shallow well .	670	18	37 : 1
" " " " .	151	4	36 : 1
" " " " .	1,560	38	41 : 1

high. Since replacing gelatin by agar for the 20° C. counts we have obtained similar results leading to the same conclusions. In Table VII are shown the averages for a large number of samples from various sources. Knowing the general ratio for any given water, any marked deviation may suggest inquiry as to the cause, but unless there is some other change the variation may be of no significance. Experience shows that, as a rule, variations in the ratio are purely accidental and have no significance whatever.

The "Coliform Count" determined on neutral-red bile-salt lactose agar is always less than the agar counts, and some average figures and ratios are shown in Table VIII.

Filtered waters should always be examined for objectionable microbes. If the standard of 100 colonies per cubic centimetre at 20° C. is slightly exceeded, the fact is of little consequence if objectionable bacteria are absent or very few in number, and the water may be passed as satisfactory; whereas if the 100 is not exceeded and the objectionable bacteria are relatively abundant, the water cannot be considered to be satisfactory. In our laboratories, filtered waters are always examined for *Bact. coli*, *Cl. welchii*, and occasionally for streptococci, and the quality of the water is judged from the results of the whole examination.

TABLE VII

AVERAGE BACTERIAL COUNTS PER 1 C.C. AND RATIOS, OF A LARGE NUMBER OF SAMPLES OF WATER FROM VARIOUS SOURCES

Waters.	Number of Samples.	Colonies per c.c.		Approx. Ratio Gelatin to Agar.
		Gelatin. 20° C.	Agar. 37° C.	
Unpolluted deep wells	344	36.5	3.2	11 : 1
Polluted deep wells	118	3,530	550	6 : 1
Shallow wells	133	3,320	372	9 : 1
Springs	109	1,110	92	12 : 1
Wells and springs (chlorinated) . .	125	14.4	2.8	6 : 1
Rivers, raw	319	8,440	1,340	6 : 1
„ excess lime treated	50	9.3	1.3	7 : 1
„ filtered and chlorinated	164	21.7	3.3	7 : 1
Sewage effluents	25	11 millions	270,000	41 : 1

TABLE VIII

RATIO OF THE BACTERIAL COUNT ON AGAR TO THE "COLIFORM COUNT" ON NEUTRAL-RED BILE-SALT LACTOSE AGAR IN CONTAMINATED WATERS

Source.	No. of Samples.	Average Agar Ct. 1 day, 1 c.c. 37° C.	Average Coliform Ct. 1 day, 1 c.c. 37° C.	Ratio.
1. River. Clear chalk water	33	68.6	14.6	4.7 : 1
2. River. Clear chalk water	34	60.1	11.7	5.1 : 1
3. Sewage-polluted upland river	50	2,166	228	9.5 : 1
4. Sewage effluents	25	270,000	41,000	6.5 : 1

In unfiltered water, the number of bacteria varies enormously, and in really good waters agar counts of 1,000 or more per c.c. may be obtained in occasional samples. The character of the source and the history of the water have always to be taken into consideration in interpreting the results. Upland and moorland surfaces, for example, usually yield waters which contain more bacteria than waters from springs and deep wells. River waters vary from day to day, and a very slight rainfall will often greatly increase the number of bacteria present.

Interpretation of the Bacterial Counts.

Too much reliance must not be placed on the mere enumeration of bacteria in water, and the formulation of standards on this basis, classifying waters as pure, impure, etc., according to the counts obtained, as has been suggested by various workers, has no general use or value.

The bacterial enumerations form only a comparatively small item in the general considerations of the source and the samples on which an opinion is founded, but in a water supply of known history, in assessing the efficiency of purification processes or the cleanliness of mains, reservoirs, etc., they have considerable value.

It must never be overlooked that the types of bacteria which are present are more important than the number. Also, the most satisfactory result obtained on bacteriological examination of a sample does not in itself justify certification of a water supply as safe, but it is a great aid in arriving at a correct conclusion if full details of the source and sample are known.

Some water supplies give entirely satisfactory bacteriological results in fine weather, but are subject to great deterioration after heavy rainfall. The bacteriological effect of rainfall on streams, springs and wells, whether shallow or deep, must be studied before an opinion can be given upon them as sources of supply. As an example of many such experiences, the effect of rainfall on the bacterial purity of a public water supply derived from springs in the Chalk formation is shown in Table IX.

TABLE IX
SHOWING VARIATION IN THE BACTERIAL PURITY OF A SPRING
WATER DUE TO RAINFALL

	Average of 192 Samples.	Sample Collected Thirty-six Hours after Heavy Rainfall.	Sample Collected during Drought.
Agar count, 1 c.c., 1 day at 37° C.	54	7,000	1
Gelatin count, 1 c.c., 3 days, 20° C.	760	32,000	87
Bact. coli—			
Present in	10 c.c.	0.01 c.c.	—
Absent in	1 c.c.	0.001 c.c.	100 c.c.
Cl. welchii—			
Present in	100 c.c.	10 c.c.	—
Absent in	10 c.c.	1 c.c.	100 c.c.

The less the effect of rainfall or floods, the more satisfactory is the stream, spring, or well, as a source of water supply; but if a careful examination of the source shows that this is satisfactory, and if few or no bacteria are found which can be identified as of intestinal origin, any turbidity produced by a heavy rain may be regarded as of comparatively harmless character.

Certain deep wells in Essex yield waters containing large numbers of bacteria, and occasionally also they contain lactose-fermenting bacteria. We have made a careful study of these wells, and our first efforts were made to discover the source of the coliform bacteria. Later we endeavoured to ascertain the reason why the bacterial counts

were usually so numerous. The wells referred to are all from 500 to 1,000 feet deep, in the open country, and pierce 300 to 500 feet of London Clay. Every possible source of pollution had been excluded by investigation. One well, which yielded the worst water bacteriologically, was particularly examined. The water was pumped out of the dug portion of the well so that samples could be obtained from the two bore tubes. Before this pumping was commenced, a sample was taken from the rising main of the well.

The results of the examination were as follows :—

		Bacteria per c.c.	
		On Gelatin.	On Agar.
Water from rising main of well	.	5,810	980
Water from No. 1 bore	.	12	8
Water from No. 2 bore	.	18	12

The temperature of the water was from 64·2° F. to 64·5° F. At a later date plates and materials were taken to the pumping station, samples were collected, a portion plated on the spot, and the remainder brought to the laboratory and kept at air temperature until next day, when another set of plates was made.

The interval between the two platings was about eighteen hours.

	Bacteria per c.c. Plated on Spot.		Bacteria per c.c. Plated 18 hours later.	
	On Gelatin.	On Agar.	On Gelatin.	On Agar.
From unsterilised tap on pumping main	690	258	Thousands.	1,780
From sterilised tap on pumping main	634	234	„	1,500
From water in well obtained by lowering bottle	Thousands.	348	„	900

The sterilising of the tap had little effect upon the results in this case, but it will be noted that both with gelatin and agar the results from the sterilised tap were a little lower in the samples plated on the spot than those from the unsterilised tap. The effect of keeping the water eighteen hours before plating was marked.

The necessity for sterilising the tap from which water is drawn (if the effect of the tap is to be excluded) was shown from the following results, obtained when examining a supply to a private house in which there was a case of typhoid fever. The tap was of large size and thickly coated inside with a slimy zoogloea of bacteria. Reference has been made to this case on p. 80.

	Colonies per c.c.		Bact. coli.
	On Gelatin.	On Agar.	
Tap unsterilised	710	30	Present in 20 c.c.
Tap sterilised	250	5	Absent in 36 c.c.

When examining the series of deep wells above referred to, samples of the water were collected for bacteriological examination in $\frac{1}{2}$ -litre wide-mouthed bottles. From each bottle a small tube of about 20 c.c.

capacity was filled, and both were packed in ice, and next day they were examined.

The results were as under :—

TABLE X

	Bottle Samples		Tube Samples	
	Colonies per c.c.			
	On Gelatin	On Agar	On Gelatin	On Agar
Well No. 1 . . .	9,600	1,640	1420	202
2 . . .	3,840	1,660	liq.	154
3 . . .	4,000	148	1420	542
4 . . .	94,000	48,000	6100	3700
5 . . .	11,520	5,400	5400	3000
6 . . .	1,600	138	490	95
7 . . .	1,520	1,540	1500	430

Speaking generally, the number of bacteria in the water in the small tubes, in which it would be cooled down quickly, was much lower than in the bottles, the water in which would require a longer time to cool down.

Upon another occasion, a day was spent at one of these pumping stations collecting samples at intervals and plating them on the spot. The results varied enormously, but, speaking generally, the water gradually improved as pumping continued.

	Bacteria per c.c.	
	On Gelatin.	On Agar.
Lowest (at termination of pumping) . . .	219	190
Highest (pumping just commenced) . . .	4,000	1,270

When all these points are considered, together with the fact that the number of bacteria may vary enormously in water from the same well, taken at different times, it is obvious that the enumeration of the bacteria from such wells is of little value. It must be remembered, however, that this refers only to certain deep wells yielding an alkaline water of a temperature of about 16° C. In other wells we have never had reason to suspect such marked variations.

We examine at frequent regular periods samples from many deep well supplies which invariably contain very few bacteria, the counts on agar being of the order of 0 to 10. In these cases, if any significant increase in the plate counts were observed, inquiry would immediately be made to ascertain the cause.

As previously stated, changes in the bacterial content may occur in samples in the interval of time between collection and examination unless suitable precautions are taken.

Besides the variation due to keeping, samples from the same bottle may give varying numbers, doubtless due to the bacteria forming

zoogloea-like masses. These minute masses are sometimes visible to the naked eye, and can be isolated and examined. Most vigorous shaking often fails to disintegrate them entirely. One sample of water examined before and after shaking gave 860 bacteria per cubic centimetre from the unshaken sample, and 4,800 from the same water after very vigorous agitation.

Enough has been said to show how little reliance can be placed on the mere enumeration of the bacteria in a sample of water, whether the bacteria are cultivated at 20° C. or at 37° C. Fortunately the number of objectionable bacteria present in water, and for which special search is made, does not vary to any appreciable extent in the usual interval between collection of the water and its examination.

The excretal bacteria for which search is particularly made are *Bact. coli*, streptococci and *Cl. welchii*, and these are individually considered in subsequent chapters.

Quantitative Considerations with Regard to Intestinal Organisms

Quantitative considerations with regard to these organisms are of the greatest concern, and far outweigh in importance the bacterial counts obtained on nutrient agar, or gelatin. There are few waters in which *Bact. coli* cannot be found if a sufficient quantity of the water be taken for examination, and other excremental organisms may on occasions be found in pure waters if samples are sufficiently often examined or large quantities used for the purpose. As the detection of sewage or manurial contamination by bacteriological methods must depend upon the discovery of the bacteria characteristic of excremental matter, a very important point remains for discussion, viz., the amount of water which should be used for the examination. Chemical analysis cannot be depended upon to detect pollution with 0.1 per cent. of sewage, or with 1 per cent. of most sewage effluents, though the latter may contain practically all the organisms of the original sewage. Bacteriological analysis may be depended upon to detect a much smaller quantity of polluting matter. Unfortunately, the number of the selected organisms found in sewage varies enormously, and the proportion of each to the others varies in every sample. In relative abundance they occur in the following order :—

	Per c.c.
<i>Bact. coli</i>	100,000 to 1,000,000
Streptococci	1,000 to 100,000
Spores of <i>Cl. welchii</i>	100 to 10,000

Assuming that efforts are limited to the detection of pollution corresponding to one-millionth part of sewage containing the minimum number of these organisms, it is obvious that 10 c.c. of the water would be required to give indication of the presence of *Bact. coli*, 1,000 c.c., or 1 litre, to afford evidence of streptococci, and 10 litres for the detection of the spores of *Cl. welchii*.

On the other hand, assuming the polluting matter to contain the maximum number of the above organisms, 1 c.c. would suffice for the detection of *Bact. coli*, 10 c.c. for streptococci, and 100 c.c. for the spores of *Cl. welchii*.

The qualitative aspect of the case really depends upon the number of the particular bacteria found in faecal matter. In stools from patients suspected to be suffering from typhoid fever we have found 1,000 million *Bact. coli* per gramme, and upon the neutral-red bile-salt lactose agar plates the proportion of streptococci to bacteria of the *coli* group was 1 to 30 or 40, which would give some 25 million streptococci per gramme. With two-millionth of a gramme the milk reaction for *Cl. welchii* was obtained. If 1 part of faecal matter of this kind were added to 10,000 million parts of water, *Bact. coli* would be found in 10 c.c.; but to detect the streptococci about $\frac{1}{2}$ litre would be required, and no less than 5 litres would have to be used to detect *Cl. welchii*. These large quantities of water cannot be conveniently used, nor, if they were used, would there be any certainty of detecting the streptococcus or the spores of *Cl. welchii*. In a dilution of 1,000 million the presence of *Bact. coli* in 1 c.c. would raise grave suspicion of pollution, and a careful examination of larger quantities of the water might be expected to reveal the presence of the two other organisms, and so conclusively prove the contamination.

In reporting to the Local Government Board on the "Bacteriological Examination of the Normal Stools of Healthy Persons," Sir Alexander Houston (1902) gave a brief approximate statement of his average results. Per gramme of fæces he found:—

Total number of bacteria on gelatin at 20° C.		
and agar at 37° C.	.	100 millions to 1,000 millions
<i>Bact. coli</i>	.	
Streptococci	.	At least 100,000 (probably an under-estimate).
<i>Cl. welchii</i> spores	.	1 million to 10 millions.

It is noteworthy that in fæces practically the whole of the living bacteria will grow on agar, forming colonies in twenty-four hours, and that the majority of these colonies consist of bacteria of the coliform group.

There is a tendency to report unfavourably upon any sample which contains coliform bacteria in 100 c.c., regardless of the number and type, and frequently the action causes a great deal of unnecessary alarm. This was said to be Houston's standard, totally regardless of the fact that he always asserted that this standard was only tentative, and to be "controlled by knowledge of local conditions." No doubt, also, Houston endeavoured to get the London water supply up to this standard of purity, but because it frequently failed to reach this high standard he did not alarm the Metropolis every time coliform bacteria or even *Bact. coli* were found in the water supplied.

References

- HOUSTON. 1902. Report of the Medical Officer to the L.G.B., 1902-3, p. 538.
- MINISTRY OF HEALTH. 1939. Reports on Public Health and Medical Subjects, No. 71. "The Bacteriological Examination of Water Supplies." (Revised Edition, January, 1939.)
- WHIPPLE. 1901. Quoted from Prescott and Winslow (1924), "Elements of Water Bacteriology," p. 27.

CHAPTER XXVIII

INTESTINAL ORGANISMS USED AS INDICES OF POLLUTION. THE COLIFORM GROUP OF BACTERIA

THE importance of *Bact. coli* in water bacteriology far outweighs that of any other organism, and no adequate opinion regarding the wholesomeness of a water can be given without knowing how many of these bacteria occur in the water.

The group of bacteria to which this micro-organism belongs, *i.e.*, the "coliform bacteria," has been extensively studied by water bacteriologists in all parts of the world, and a voluminous literature concerning their origin, characteristics and significance has resulted. Doubts have from time to time been cast on the validity of *Bact. coli* as an indicator of faecal contamination, but the opinion still remains unshaken that *Bact. coli*, adequately defined, is the most delicate and certain indicator of excretal pollution at our disposal. In this connection, no more authoritative opinion can be quoted than that of the late Sir Alexander Houston (1925), who stated: "The *B. coli* test, having now survived the vicissitudes of an earlier time, stands to-day as the most practical and delicate and rapid test for excremental filth, and may surely be taken as the most reliable indicator, in its positive aspects, of possible danger, and, in its negative aspects, of the almost certain absence of microbes associated with epidemic water-borne disease, and, generally speaking, as the one test which, above all others, it is least excusable for a water analyst to omit." In our experience, this opinion still holds good.

Since water-borne infections are essentially dependent on excretal pollution, the detection of such contamination in water becomes almost exclusively the prime object of bacteriological examination, and on this fact rests the supreme importance of *Bact. coli*, and the necessity for ready and accurate methods for its isolation, identification and quantitative estimation. Much of the confusion that has occurred regarding this organism is due to the following facts:—

1. The various other members of the coliform group are morphologically similar to *Bact. coli* and share with it many cultural properties.
2. The term "*B. coli*" used to be, and by some authorities still is, loosely employed to include the whole coliform group, the expression "typical *B. coli*" being more or less synonymous with "*Bact. coli*" as now understood, and "atypical *B. coli*" referring to the other coliform bacteria.
3. The term "*Bact. coli*" does not refer to one particular organism, as, for instance, the "*B. coli communis*" of Escherich, but includes quite a number of coliform bacteria which normally predominate in human and animal excrement, and which are distinguishable from the remainder of the coliform group by certain definite characteristics. The various strains collectively termed "*Bact. coli*," however, present individual differences in their biochemical reactions which have caused much confusion in the past.

The limited importance of these differences is now appreciated, and much of what was at one time thought to be "variation" or "instability" in a single bacterium is now realised to be merely the insignificant dissimilarities between members of a compact group, which is justifiably treated in water bacteriology as one organism, under the generic title of *Bact. coli*.

4. As *Bact. coli* tends to die when removed from its natural habitat, the presence of this organism in sufficient numbers in water justifies the assumption of recent faecal pollution. Some of the coliform bacteria, however, are widely distributed in nature, and may gain access to water from non-faecal sources. Their presence in water *may*, therefore, be of little significance. On the other hand, as a result of their wide distribution, they are normally present in many foodstuffs and can thereby gain entrance to the human and animal intestine. That small numbers of these organisms are frequently found in faeces is not, therefore, surprising. Moreover, like other bacterial inhabitants of the soil and vegetation, they are capable of maintaining their existence in water for long periods, and can thus outlive much greater initial numbers of *Bact. coli*. Their presence in water, in the absence of *Bact. coli*, while not necessarily indicative of faecal pollution, may point to a remote excremental contamination from which *Bact. coli* has disappeared. Doubts have been raised by Bardsley (1934) and others, as to whether even these "atypical" coliform bacteria are ever completely dissociated from faecal contamination.

It becomes essential, therefore, to ascertain as precisely as possible the distinctive properties of *Bact. coli*, the maximum extent of any possible variation, and the most reliable laboratory methods of distinguishing it from the other members of the coliform group.

It is universally recognised that the excreta of man, mammals, fish and birds contain *Bact. coli* in enormous numbers (100 millions to 1,000 millions per gramme), but there has been much controversy on the possibilities of the existence and multiplication of this organism in non-faecal matter. Much research has been concentrated on this point, but, although valuable additional differential tests have been devised and new facts elicited regarding the distribution of the coliform bacteria in nature, no adequate evidence has been advanced to prove the existence of *Bact. coli* in sites entirely removed from the possibility of faecal pollution. We maintain the view, therefore, that *Bact. coli* is found only in waters which are liable to direct or indirect contamination by matter originating in the human or animal intestine. Also, since *Bact. coli* does not flourish under the usual conditions of water supplies but slowly succumbs, its presence in sufficient numbers demonstrates the pollution to be continued or fairly recent. Conversely, waters from sources subject to no immediate pollution are, generally and for practical purposes, free from *Bact. coli*.

A minor limitation to the value of demonstrating *Bact. coli* in water supplies is that the source of the excrement—namely, whether from man, beast or bird—cannot be distinguished, for no means have yet been devised to effect this differentiation. The real danger to water supplies lies not in *Bact. coli*, *per se*, but in its possible association in faecal matter with organisms of disease. In this respect, human excrement is by far the most dangerous, but it is rightly assumed that *all* cases of excretal pollution of water supplies are potentially dangerous to the consumers.

The determination of pathogenicity and the application of serological reactions are, unfortunately, of no practical value in the differentiation of the bacteria of this group. Reliance has, therefore, to be placed on morphological and biochemical characteristics, and these, although subject to a certain degree of natural and artificial variation, are, in the opinion of most experienced bacteriologists, sufficiently fixed to be of great value.

Though many attempts have been made, no completely satisfactory classification of the coliform bacteria has yet been accomplished, and the possibility of ultimate success is still remote, as the members of the group are so closely interlinked that subdivision, unless carried to the extreme separation of the multitude of insignificantly different strains, must be limited to a somewhat arbitrary "rough sorting" into subgroups. Fortunately, the distinction between *Bact. coli* and the other coliform bacteria is well-marked, and the broad divisions tentatively suggested by the Ministry of Health Committee (1939) are of considerable value in the sphere of practical water bacteriology. These "types" are discussed later, but the salient characteristics common to all members of the coliform group may be noted here.

The "coliform bacteria" are Gram-negative, non-sporing, rod-shaped micro-organisms, capable of growing in the presence of bile-salt (*i.e.*, "bile-tolerant") and of fermenting glucose and lactose with the production of acid and gas. They are easily cultivated, either aerobically or anaerobically, on ordinary laboratory media and produce, *e.g.*, on nutrient agar, more or less similar growths which are devoid of any definite pigment. Growth on gelatin is not usually accompanied by liquefaction.

By their ability to produce acid and gas from lactose, the coliform bacteria are distinguished from the larger group (of Gram-negative, non-sporing, bile-tolerant rods) which includes many organisms of disease, such as the typhoid, paratyphoid, salmonella and dysentery bacteria. The infallibility of this distinction has not escaped criticism, and various strains of glucose-fermenting, non-lactose-fermenting "colon bacilli" (or "paracolon bacilli") have been described. Mackie (1913) put forward the view that lactose-fermentation is no more important than any other sugar reaction in the differentiation of the coliform group, but this view is not generally shared, and, as far as water bacteriology is concerned, we should reject from the coliform group any bacteria which failed to produce acid and gas in lactose medium.

Besides possessing the above "cardinal" properties, all the coliform bacteria have wide fermentative powers and can usually produce acid and gas from the following "sugars": fructose (*i.e.*, *lævulose*), galactose, mannose, maltose, dextrin, arabinose, rhamnose, xylose, mannitol and sorbitol. Sucrose, raffinose, starch, inulin, dulcitol, adonitol, inositol and salicin are variously fermented by different members of the group and are used in attempts to differentiate the particular strains. These reactions are, however, of subsidiary importance in water bacteriology.

In the great majority of cases, fermentation of lactose by the coliform bacteria is rapid, but the action may sometimes be delayed. It is an interesting fact in connection with the pathogenicity of most of the non-lactose-fermenters and the non-virulence of the lactose-fermenters, that in forty-nine cases of unusually severe *Bact. coli* infections of the urinary tract described by Dudgeon (1924) all the strains of *Bact. coli* isolated were of a slow lactose-fermenting type. As a general rule, however, it is our practice to reject as free from coliform bacteria any water-inoculated lactose cultures which fail to show acid and gas after forty-eight hours' incubation at 37° C.

CLASSIFICATION OF THE COLIFORM GROUP

A large number of tests have been devised with the object of separating the group into its constituent members, and it can be said that the greater the number of tests used by any observer, the greater the number of strains he will find. Thus, MacConkey (1909), using seven tests, isolated thirty-six varieties out of a possible number of 128 (2⁷), and Levine (1921) has pointed out that, with ten characters under observation, over 1,000 combinations are possible. For the purposes of practical water bacteriology, however, comparatively few tests need be used, and six are suggested by the Ministry of Health Committee, as Table I (taken from Report No. 71), shows :—

TABLE I
DIFFERENTIATION OF THE COLIFORM GROUP

Classification of the Ministry of Health Committee.	Methyl-red reaction.	Voges-Proskauer test.	Growth in citrate.	Production of indole.	Gas in MacConkey lactose broth at 44° C.	Gelatin liquefaction in 7 days at 20° C.	Probable habitat.
<i>Bact. coli</i> , type I, faecal	+	—	—	+	+	—	Human and animal intestine.
<i>Bact. coli</i> , type II	+	—	—	—	—	—	Doubtful ; probably not primarily intestinal.
Intermediate, type I	+	—	+	—	—	—	Mainly soil.
Intermediate, type II	+	—	+	+	—	—	Mainly soil.
<i>Bact. aerogenes</i> , type I	—	+	+	—	—	—	Mainly vegetation.
<i>Bact. aerogenes</i> , type II	—	+	+	+	—	—	Mainly vegetation.
<i>Bact. cloacæ</i>	—	+	+	—	—	+	Mainly vegetation.
Irregular, type I	+	—	—	+	—	—	Human and animal intestine.
Irregular, type II	+	—	—	—	+	—	Doubtful.
Irregular, other types	Reactions variable						Doubtful.

The recommended procedures for the performance of these tests are as follows :—

1. **Methyl-red Test.** The bacteria are grown in glucose phosphate peptone solution (see Appendix) and, after two to five days' incubation at 37° C. (two days are usually sufficient), a few drops of methyl-red solution (see Appendix) are added. A red coloration of the culture denotes a positive reaction, and a yellow colour a negative reaction.

The methyl-red-positive bacteria produce and maintain a hydrogen-ion concentration of at least pH 4.5, whereas the methyl-red-negative group induce a lower initial hydrogen-ion concentration and soon cause, by the production of carbonates, a reversion to neutrality, methyl-red turning yellow at pH 6. The test was elaborated by Clark and Lubs (1915) in confirming the findings of Smith (1895) regarding the ratio of CO₂ to H₂ in the gas produced by fermentation and the resulting acidity.

2. **Voges-Proskauer Test.** The bacteria are grown in glucose broth (see Appendix). Alternatively the glucose phosphate peptone solution used in the methyl-red test may be employed. At the end of two days, 5 c.c. of a 10 per cent. solution of potassium hydroxide are added and the tube allowed to stand exposed to the air at room temperature for twenty-four hours. A red eosin-like fluorescence slowly appears with cultures of the aerogenes-cloacæ organisms.

The reaction is ascribed by Harden (1906) to the production from glucose of acetyl-methyl-carbinol which, in the presence of alkali, is oxidised by atmospheric oxygen to diacetyl. This product is considered to react with a constituent of the peptone in the broth and so to produce the characteristic fluorescence.

As compared with the test just described, the modification introduced by O'Meara is more rapid, more convenient and at least as reliable. A knife-point of creatine is added to the forty-eight hours' culture, followed by 5 c.c. of 40 per cent. sodium hydroxide, and the tube is plugged with a rubber stopper and vigorously shaken. The stopper is then removed and the tube left on the bench. In positive reactions, a pink colour, without fluorescence, develops within half an hour; the absence of colour in that time denotes a negative reaction.

3. **Growth in Citrate.** To the citrate medium (see Appendix) is added a very minute inoculum of a solid culture (or preferably a very small loopful of a four to six hours' peptone water culture). The tube is then incubated at 37° C. for twenty-four hours, or, if no growth has occurred, for forty-eight hours.

The rationale of the test (Koser, 1926) is that *Bact. coli* is unable to utilise sodium citrate as its sole source of carbon, whereas the other coliform bacteria (being accustomed to analogous circumstances in the soil and elsewhere) can do so.

Some experience is required in the interpretation of this test. Where the tube is clear, a negative reaction can safely be inferred, and the great majority of the intermediate-aerogenes-cloacæ types produce within twenty-four hours a very distinct turbidity. Moreover, it is our experience that tubes which are definitely negative after twenty-four hours do not become positive even in ten days. It is recognised, however, that certain varieties of *Bact. coli* can grow to a slight extent in the medium and produce a faint opalescence which may be mistaken for a positive result. It is for this reason that the smallest possible inoculum should be introduced and that all dubious results should, for safety, be regarded as negative unless, on further incubation, a fair turbidity develops. The addition to the medium of bromo-thymol-blue has been advocated as a help in such difficult cases, positive results becoming blue or bluish green and negative results remaining green. Our experience, however, is that a doubtful opacity is accompanied by an equally doubtful colour change.

4. Indole Test. The bacteria are grown in peptone water (see Appendix) for three days at 37° C. A few drops (0.5 c.c.) of Erlich's reagent (see Appendix) are then added. In positive cases, a red or pink colour develops within two minutes at the interface of the two liquids. As by this method the "rosindole" is concentrated in one layer, weak results are most easily detectable. The majority of indole-positive coliform bacteria produce sufficient indole to render the test positive within twenty-four hours, but up to 10 per cent. of *Bact. coli* strains isolated from water require three days (and in a very few cases the test may become positive only on the ninth or tenth day). A saving of time can often, therefore, be effected by inoculating duplicate tubes, testing one after twenty-four hours, and retaining the second only when the first shows a negative reaction.

5. 44° C. "MacConkey" Test. A tube of MacConkey lactose broth is warmed to temperature, inoculated with the organism under examination, and then incubated in a 44° C. water-bath for forty-eight hours. Gas production within this period is regarded as a positive result; absence of gas after forty-eight hours, despite the presence of growth or acidity, is considered a negative result.

A positive response is claimed to be practically specific for *fæcal coli*. It has yet to be proved, however, that all strains of *fæcal coli* are capable of producing gas at this temperature and that other bacteria cannot do so.

For success with this test, the temperature in the medium must be kept constant at 44° C. (*i.e.*, with a maximum permissible variation of $\pm 0.5^\circ$ C.) For this purpose, an accurately regulated water-bath is essential and even recording thermometers are recommended. It is a useful precaution to include, as controls, two tubes of the medium inoculated respectively with a known positively-reacting strain of *Bact. coli*, type I, and a known negatively-reacting *Intermediate* or *aerogenes* organism.

6. Liquefaction of Gelatin. A stab inoculation into the solid gelatin medium (see Appendix) is incubated at 20° C. The massive inoculation method first suggested by MacConkey helps to hasten results. The tube is examined periodically for evidence of liquefaction of the medium. Some strains of *Bact. cloacæ* can produce the change within the seven days but the majority require at least twenty-one days, and a negative result should not be accepted within this period.

In systematic classification, these differential tests would, of course, be applied to pure cultures of coliform organisms only after the group characteristics had been confirmed. In water bacteriology, where mixed cultures are invariably present in the primary MacConkey lactose broth tubes, the various bile-tolerant organisms are isolated by plating on, for instance, neutral-red bile-salt lactose agar, and the selection therefrom of red colonies ensures the ability to produce at least acid in lactose. Before, however, any organism at this stage can be recognised as belonging to the coliform group, its morphology has to be checked and its power to produce both acid and gas in lactose still remains to be proved. The organism having been microscopically verified to be a Gram-negative, non-sporing rod (and the purity of the colony thereby also attested), it suffices to augment the differential tests by a confirmatory lactose-fermentation test:—

7. Fermentation of Lactose. Inoculation of a tube of MacConkey lactose broth is followed by incubation at 37° C. for twenty-four hours, and, if no gas has been produced, for a further twenty-four hours. If gas is still absent

after forty-eight hours, the organism has little claim to belong to the coliform group, and whatever the results of the differential tests the presence of such an organism in water would be regarded by us as of much less significance than that of true lactose-fermenters.

In actual practice, the number of tests suggested by the Ministry Committee can safely be curtailed, as not all are indispensable, and some, in fact, possess distinct disadvantages. The gelatin reaction, for example, is not a practical proposition for routine work. Apart from the fact that the great majority of organisms of the *Bact. cloacæ* class require much longer than seven days (in some cases up to six months) to produce liquefaction of the gelatin, the value, in this country, of distinguishing between *Bact. cloacæ* and *Bact. aerogenes* (type I) is negligible as compared with the delay involved. The Voges-Proskauer test may also be omitted as many observers besides ourselves have noted the almost perfect inverse correlation between it and the more convenient methyl-red test. The 44° C. MacConkey lactose test (which is a modification of the original technique of Eijkman, 1904) shows promise of being a useful confirmatory test, or possibly even of replacing some of the other tests for defining *Bact. coli*—where suitable laboratory facilities are available. The water-bath should, for instance, be kept in a temperature-controlled incubator, and opened not more than once daily. Until simpler apparatus can be devised to replace the elaborate equipment now required, the general usefulness of this test must remain somewhat limited. Rigid adherence to the prescribed technique is essential, and the Ministry Committee recommend omission of the test where the requisite apparatus is not available.

TABLE II

	Citrate.	M.R.	Indole.	Probable habitat.
<i>Bact. coli</i> , type I, faecal and Irregular, type I	} —	+	+	{ Human and animal intestine.
<i>Bact. coli</i> , type II and Irregular, type II	} —	+	—	Doubtful.
Intermediate, type I .	+	+	—	{ Mainly soil.
Intermediate, type II .	+	+	+	
<i>Bact. aerogenes</i> , type I and <i>Bact. cloacæ</i>	} +	—	—	{ Mainly vegetation.
<i>Bact. aerogenes</i> , type II .	+	—	+	
Irregular, other types .	Reactions variable			Doubtful.

In the majority of waterworks laboratories, therefore, the differential and confirmatory tests may be reduced to :—

- (a) Lactose-fermentation test ;
- (b) Citrate test ;
- (c) Methyl-red test ;
- (d) Indole test ;

and, (a) being ascertained, the Ministry Table could be rewritten as in Table II.

Consideration of the above Table raises doubts regarding the virtue of distinguishing between *Bact. coli* I and Irregular I, as their origin and, therefore, their sanitary significance would appear to be the same, and reference to Table I shows that the 44° C. test forms the only basis for the distinction. The same criticism might be applied, though with less vigour, to the differentiation between *Bact. coli* II and Irregular II, but, as the habitat of each is uncertain, they may be found to differ in significance. Until further information becomes available, we consider it advisable to regard both *coli* II and Irregular II as possible faecal organisms, *i.e.*, as variants of *coli* I, which have for some reason lost the power of producing indole. It would seem probable that Irregular II, which can produce gas at 44° C. and which differs, therefore, from *coli* I only as regards indole-production, may prove to be a more significant organism than *coli* II, which differs from *coli* I as regards both indole and the 44° C. test.

The practice, too, of differentiating between the various intermediate-aerogenes-cloacæ types would also appear to be somewhat unnecessary as, in this country at least, the importance of one is neither more nor less than that of any other of the citrate-positive types.

The question of interpretation might, therefore, logically resolve itself into employing the citrate test alone and attaching excremental significance only to the citrate-negative organisms. In the differentiation of the coliform group, however, no test is so fundamental that complete reliance can be placed solely upon it, and, as already stated, there are occasions when the citrate test gives a somewhat dubious result. The bare minimum of tests must, therefore, include the methyl-red reaction and interpretation would follow on these lines :—

TABLE III

Citrate.	M.R.	Significance.	Types.
—	+	Predominantly or possibly faecal.	<i>Bact. coli</i> , I and II. Irregular, I and II.
—	—	Doubtful.	Irregular, other types.
+	±	Mainly non-faecal.	Intermediate, I and II. <i>Bact. aerogenes</i> , I and II. <i>Bact. cloacæ</i> .

The indole test is by no means superfluous, however. It is extremely useful in distinguishing the two types of *Bact. coli*, a positive reaction, in such cases, giving the much stronger assurance of faecal origin. On the comparatively few occasions, too, when the reactions of Intermediate, type II, are obtained, attention is at once redirected to the citrate tube, to verify that the growth is sufficient definitely to exclude *Bact. coli*, type I.

CHARACTERS OF THE COLIFORM BACTERIA

1. *Bact. coli*, type I

Morphology. The size is very variable, from forms almost coccoid to threads. Usually the rods are 2 to 3 μ in length and 0.5 μ in breadth. They are readily stained, and are Gram-negative and non-spore-forming. Only exceptionally can the presence of capsules be observed, the great majority of strains being permanently non-capsulated.

Motility is usually present, but is often sluggish. It is well observed in a broth culture after twenty-four hours' growth at room temperature. It may be lost or recovered in many cases, and is not fundamental. Permanently non-motile forms have been described, such as *Bact. coli* immobile.

Cultivation. Growth is readily obtained on ordinary media under aerobic or anaerobic conditions, being much more profuse in the former. The temperature range is from 10° C. to 46° C., with the optimum about 37° C. A neutral reaction is most favourable, but growth occurs over a wide range, from about pH 4.5 to 9.

There is nothing characteristic about the growths on agar, gelatin or in broth. On agar medium, *Bact. coli* appears as a profuse, usually moist growth, slightly raised and of a translucent whitish colour which by transmitted light may present a bluish tinge. The colonies are usually round, smooth, raised and slightly convex with a shiny, pearly appearance, but rough varieties sometimes occur and have a more spread-out, flat, irregular shape with a dull, dry, granular aspect. The appearances on gelatin medium are similar and no liquefaction occurs. In nutrient broth, uniform turbidity usually develops, except with the rough variety which gives a deposit in a clear broth.

Arkwright (1921) described the smooth (S) and rough (R) varieties of bacterial colonies and demonstrated the importance of this distinction in the typhoid, paratyphoid and other pathogenic bacteria. The same significance does not appear to apply to *Bact. coli* in water bacteriology. Sub-cultures on neutral-red bile-salt lactose agar from primary lactose tubes not infrequently show rough colonies either alone or in association with smooth colonies. The rough types are as readily killed by chlorination of the water as are the smooth.

Special Media. MacConkey's neutral-red bile-salt lactose agar, Endo's agar, and eosin-methylene-blue agar (see Appendix) are valuable media for the isolation and study of *Bact. coli*. We prefer the first-named, and on it *Bact. coli*, type I, appears as a circular, slightly

raised colony, the centre of which is red and gradually shades off to a pale pink, semi-transparent periphery. On Endo's medium the organism grows as a red colony and on eosin-methylene-blue agar as an almost black colony with a thin, lighter periphery, and showing a metallic sheen by reflected light. Neighbouring colonies of coli I on these media generally do not tend to coalesce, but remain discrete and are described as "non-mucoid." Exceptionally, however, the colony may present a gelatinous or "mucoid" appearance, somewhat similar to the typical description of *Bact. aerogenes*, but this is such an infrequent occurrence that, for practical purposes, coli I may be regarded as non-mucoid.

Biochemical Reactions. 1. *Fermentation*, with the production of acid and gas (CO_2 and H_2 in the ratio of 1 : 1), takes place according to Table IV :—

TABLE IV
FERMENTATIVE REACTIONS OF BACT. COLI, TYPE I

	All strains.	Most strains.	Some strains.	Few strains.	No strains.
Hexoses . .	glucose lævulose galactose mannose				
Disaccharides .	lactose maltose		sucrose	cellobiose	
Trisaccharide .			raffinose		
Polysaccharides	dextrin		starch		inulin
Pentoses . .	arabinose rhamnose xylose				
Alcohols . .	mannitol sorbitol	dulcitol		adonitol	inositol
Glucoside .			salicin		

It will thus be seen that, apart from the substances fermented by all coliform bacteria, no "sugar" is constantly fermented by coli I. Except for coli II, all other types have wider fermentative powers.

2. *Litmus milk*: acid and clot are produced.

3. *Indole* is formed in peptone water.

4. *Voges-Proskauer reaction*: negative.

5. *Methyl-red reaction*: positive.

6. *Citrate test*: negative.

7. *Utilisation of uric acid*: negative.

8. *Reduction of nitrates*: nitrites are produced.

9. *44° C. test*: positive.

Reduction of Dyes. Dyes such as neutral-red and methylene-blue

are reduced by the growth of Bact. coli to leuco-bases with loss of colour which can be restored by aeration. The fluorescence produced as a result of this reduction in neutral-red media was employed by Houston as a test for "typical B. coli," but neither this reaction nor the reduction of methylene-blue is specific for Bact. coli.

Viability. Bact. coli is readily destroyed by heat, a period of ten minutes at 60° C. or thirty minutes at 55° C. being sufficient for their destruction. Freezing does not kill them. When suspended in clear and bright water they are rapidly killed by the actinic rays of bright sunshine or the quartz mercury-vapour lamp. Weak acids and alkalies, and the ordinary disinfectants, *e.g.*, phenol, chlorine, etc., destroy them comparatively easily.

CONCENTRATIONS OF DIFFERENT SUBSTANCES NECESSARY TO INHIBIT THE GROWTH OF BACT. COLI

(Modified from Topley and Wilson, 1936)

Substance.	Concentration in peptone water.
Chlorine water	1 : 2,500
Chloramine-T	1 : 2,000
Phenol	1 : 500
Mercuric chloride	1 : 1,000,000
Flavine	1 : 1,300

As compared with the remainder of the coliform group (and the typhoid-paratyphoid group), Bact. coli is more easily inhibited by the action of certain green dyes, particularly brilliant green.

Exceedingly minute amounts of certain metals, such as copper and silver, will kill Bact. coli suspended in distilled water, and some salts exert an inhibitory or destructive action.

INHIBITORY CONCENTRATION OF CERTAIN SALTS

(Winslow and Hotchkiss, 1922)

Calcium chloride	0.5 M.
Magnesium chloride	0.5 M.
Sodium chloride	3.0 M.
Ammonium chloride	1.0 M.
Potassium chloride	4.0 M.

Bact. coli tends to die out fairly rapidly in distilled water and the reaction (*pH*), besides lack of nutrition, was shown by Winslow and Falk (1923) to be an important factor.

VIABILITY OF BACT. COLI IN DISTILLED WATER AFTER NINE HOURS AT 37° C.

(From Topley and Wilson, 1936)

<i>pH</i>	4.0	5.0	6.0	7.0	7.5	8.0
Percentage of Bact. coli surviving .	1	82	106	54	35	12

A reaction of pH 6.0 is thus the most favourable for the survival of *Bact. coli* in distilled water.

A few strains of *Bact. coli* may remain alive for several months when simply dried or placed in the soil, but no multiplication therein is known to take place.

Pathogenicity. *Bact. coli* is essentially a saprophytic inhabitant of the mammalian intestine, and only exceptionally develops pathogenic properties, as, for instance, when it infects the urinary tract.

Varieties of *Bact. coli*. The isolation and study of individual strains of *Bact. coli* form no part of the routine work of the water bacteriologist, but it may be of interest to record the reactions of certain strains, to which names have been given in the past, and which are still regarded as being the most commonly occurring varieties of faecal coli. Since MacConkey's classical work in 1905-1909, no significant advance has been made in respect of individual strains. Some slight confusion has, in fact, been introduced, though the classification of the coliform group itself has been greatly clarified. MacConkey's comprehensive investigation suffers to-day from the fact that the citrate test was not then devised, but, by careful study of the other characteristics he recorded, it is possible with a fair degree of certainty to separate the strains of Intermediate II from those of coli I, and Intermediate I from coli II.

TABLE V
STRAINS OF "*BACT. COLI*"
(Modified from MacConkey, 1909)

Number and name quoted by MacConkey.		Tests used by MacConkey.								Name now applied.
		Motility.	Indole.	Voges-Proskauer reaction.	Gelatin Liquefaction.	Inositol.	Adonitol.	Sucrose.	Dulcitol.	
No.	Name (if any).									
1		*	+	+	-	-	+	-	-	<i>Bact. acidilactici</i>
2	<i>B. acidilactici</i>	*	-	+	-	-	+	-	-	
4	<i>B. Grünthal</i>	*	+	+	-	-	-	-	-	<i>Bact. grūnthali</i> <i>Bact. vesiculosum</i>
5	<i>B. vesiculosus</i>	*	-	+	-	-	-	-	-	
33			+	+	-	-	+	-	+	<i>Bact. coli commune</i>
34	<i>B. coli communis</i> , <i>B. cavioides</i>	*	+	+	-	-	-	-	+	
35	<i>B. Schaffneri</i>		-	+	-	-	-	-	+	<i>Bact. immobile</i>
71	(<i>B. coli communior</i>)	*	+	+	-	-	-	+	+	<i>Bact. coli communius</i> <i>Bact. neapolitanum</i>
72	<i>B. Neapolitanus</i>	*	-	+	-	-	-	+	+	
66			-	+	-	-	+	+	+	
106			+	+	-	-	-	+	-	<i>Bact. coscoroba</i>
107	<i>B. coscoroba</i>		-	+	-	-	-	+	-	

On this basis, the reactions of MacConkey's strains of *Bact. coli* are reproduced in Table V.

Though nine reactions appear in this table, only four are variable, hence the maximum possible number of strains, using these criteria, is 2^4 or 16. MacConkey obtained, from human and animal faeces, sewage, water, soil and various grains, etc., the twelve listed above. We have, in a recent and comparatively small-scale experiment, isolated from water supplies alone seven of these strains (marked with an asterisk) together with two outside MacConkey's list, all giving a negative citrate reaction and thereby conforming to *Bact. coli*.

B. coli communis is the most prevalent coliform organism in faeces, and differs from the next commonest strain, *B. coli communior*, only in not fermenting sucrose. As a whole, the motile varieties far outnumber the non-motile, but *B. vesiculosus*, though non-motile, would appear to be the third commonest strain.

Later workers, notably Winslow, Kligler and Rothberg (1919), having advocated the use of salicin in addition, or rather in preference, to dulcitol, arrived at the conclusion that only seven varieties could be definitely accepted. These, with the reactions by which they can be differentiated, are shown in Table VI:—

TABLE VI
STRAINS OF BACT. COLI, ACCORDING TO WINSLOW *et al.*

	Motility.	Adonitol.	Sucrose.	Salicin.	Dulcitol.
<i>Bact. acidilactici</i>	—	+	—	—	—
<i>Bact. grunthal</i>	+	+†	—	—	—
<i>Bact. coli commune</i>	+	—	—	+	+
<i>Bact. immobile</i>	—	—	—	+	+
<i>Bact. coli communis</i>	+	—	+	—	+
<i>Bact. neapolitanum</i>	—	—	+	+	—*
<i>Bact. coscoroba</i>	—	—	+	—	+†

* “+” in MacConkey's classification.

† “—” in MacConkey's classification.

In his comprehensive study of the coliform group, Malcolm (1938) did not find salicin so useful as dulcitol, and drew attention to the fact that even the classical strains of *Bact. coli* (e.g., *Bact. coli communis* and *Bact. coli commune*) varied in their salicin reactions. It would certainly appear that the introduction of salicin adds little of assistance but rather more confusion in disturbing the already established dulcitol results. Thus, comparison of Tables V and VI shows that the organisms quoted by MacConkey as *B. neapolitanus* and *B. coscoroba* have been re-named *Bact. coscoroba* and *Bact. neapolitanum* respectively by Winslow *et al.*, who have also attributed to *Bact. grunthal* a positive adonitol reaction which this strain did not possess in MacConkey's time, but for which provision was made in MacConkey's type No. 1.

2. *Bact. coli*, type II

This subgroup closely resembles *Bact. coli*, type I, and the few differences can be summarised as follows :—

Morphology. The presence of capsules is more frequently seen, though the majority do not show this phenomenon. Motility is not so commonly found.

Cultivation. Colonial appearances are more often mucoid and confluent in character. Such colonies, on MacConkey's agar might easily be mistaken for *Bact. aerogenes* if reliance were placed on colony characters. Non-mucoid colonies on MacConkey agar closely resemble those of *Bact. coli*, type I, but typically show a wider and paler periphery.

Biochemical Reactions. The essential difference between this type and type I is that indole is not formed. The 44° C. test also is negative. Fermentation reactions are on the same lines as those of coli I, and it might be hazarded that every strain of coli I has its indole-negative equivalent.

With these exceptions, *Bact. coli*, types I and II are indistinguishable.

Varieties of *Bact. coli*, type II. It would seem that MacConkey obtained only four strains, three motile and one non-motile. These are :—

No. 7—	the indole-negative equivalent of <i>Bact. grūnthal</i> .
No. 74—	„ „ „ „ „ <i>Bact. coli communius</i> .
No. 109—	„ „ „ „ „ No. 106.

The non-motile strain, *Bact. mutabile* (MacConkey No. 8, *B. coli mutabilis*), is apparently the indole-negative equivalent of *Bact. vesiculosum*, and shows a curious phenomenon which is exhibited also by other members of the coli-typhoid-dysentery group, and which was first described by Massini in 1907. It forms white or non-lactose-fermenting colonies on MacConkey's agar, but after three days' incubation, red or lactose-fermenting papillæ appear. The procedure is permanently repeated with subculture of the white peripheral portions of the colonies, but subculture of the red papillæ constantly produces only red colonies of ordinary lactose-fermenting bacteria. It appears, therefore, that when grown on a lactose medium this late-lactose-fermenting coliform organism gives rise to some descendants which are possessed of the permanent power to ferment lactose in the usual time.

Though there is little evidence to support the view, it is possible that many varieties of coli II represent the corresponding strains of coli I which have lost the power of indole-production (and of gas-production at 44° C.) owing to unfavourable environment. In this connection, it may be of significance that of 1,636 strains of coliform bacteria which Malcolm (1938) isolated from bovine fæces and milk (which is an excellent natural medium for bacteria) he obtained only seven organisms giving the reactions of coli II, whereas from water we obtain 4 per cent. of *Bact. coli*, type II (see Table XIII).

3. Intermediate, type I

The intermediate organisms were so named because they resemble *Bact. coli* in many respects, but also share some of the characteristic, of *Bact. aerogenes*. Thus, in the Ministry of Health Committee's classification, the only essential difference between Intermediates type I, and *Bact. coli*, type II, is that the former is capable, like *Bact. aerogenes*, of growing in citrate. The organisms of this subgroup fall more or less naturally into two classes, according to their action on inositol (Malcolm, 1938).

Non-inositol-fermenting strains are almost always motile and non-encapsulated. On nutrient media, they form non-mucoid colonies which remain discrete and are generally smaller than those of *Bact. coli*. Gelatin is not usually liquefied. Colonies on MacConkey's agar are very often indistinguishable from those of *Bact. coli*, type I, and the biochemical reactions are also substantially those of *Bact. coli*. Thus, adonitol and inulin are not fermented, while sucrose, raffinose, salicin and dulcitol are variously attacked by different strains.

Inositol-fermenting strains, of which *Bact. friedlanderi* is an example, are as a rule non-motile and encapsulated. They may be regarded as methyl-red-positive varieties of *Bact. aerogenes*, type I. Colonies on agar are mucoid and quickly coalesce, and on MacConkey agar the colonies acquire the thick, mucoid and confluent appearance of *Bact. aerogenes*, though they tend to retain, rather than lose, the pink colour. Gelatin is again seldom liquefied. The biochemical reactions of *Bact. aerogenes*, type I, are closely followed inasmuch as adonitol, sucrose and raffinose are always fermented, salicin sometimes, and inulin seldom affected. Dulcitol-fermentation takes place with relative infrequency but this reaction is not so unusual as in the case of *Bact. aerogenes*, type I. These strains are less often found in water than the non-mucoid, non-inositol-fermenting varieties.

The study of individual strains of this heterogeneous subgroup is of doubtful value and has not, as yet, been pursued to any great extent. From various samples of water we have isolated citrate-positive strains corresponding in all respects to MacConkey's types, Nos. 7, 74 and 109 (*cf.* the citrate-negative varieties quoted under *Bact. coli*, type II), and Nos. 36 and 70 which liquefy gelatin. These are representative of the inositol-negative class. MacConkey's examples of the inositol-positive class are No. 99 and No. 68 (termed by him "*B. friedlanderi*"), and we have found these also in water.

4. Intermediate, type II

This subgroup, which may be regarded as consisting of citrate-positive varieties of *Bact. coli*, type I, admits of similar subdivision as that applied to Intermediate, type I, but is of so infrequent occurrence as to require only brief reference. Inositol-negative strains closely resemble *Bact. coli*, type I, and the inositol-negative varieties of Intermediate, type I, differing from the former by growing profusely in citrate medium and from the latter by producing indole. Any of the MacConkey strains cited under *Bact. coli*, type I, may be simulated

by these strains. Inositol-positive strains, which give mucoid colonies and tend to ferment all the "sugars" except dulcitol, are represented in MacConkey's list only by No. 101.

5. *B. aerogenes*, type I

Escherich, who discovered "*B. coli*" in 1885, described in 1886 the association with it, in the fæces of milk-fed infants and animals, of a somewhat similar bacterium which he called "*B. lactis aerogenes*." He noted the non-motility of this latter organism and its greater activity in the clotting of milk, a substance in which it frequently occurs and for the souring of which it is often largely responsible. Many closely related strains have since been found, and the subgroup to which they all belong, and of which *B. lactis aerogenes* (Escherich) is the characteristic member, has been named *Bact. aerogenes*, the term "*lactis*" having been omitted when it was realised that these organisms are not only associated with fæces and milk, but have a very widespread distribution. The comparatively few strains which can form indole are segregated under the heading *Bact. aerogenes*, type II, but the majority, including the original organism, do not have this property and are described as follows:—

Morphology. Gram-negative, non-sporing rods which are shorter and plumper than *Bact. coli*, usually non-motile and frequently encapsulated, especially when cultivated in milk.

Cultivation. Growth occurs readily under the same conditions as *Bact. coli*, and liquefaction of gelatin does not take place. The colonies very frequently develop a gelatinous or mucoid appearance, are often viscid in character and rapidly coalesce. The odour of the growth is usually quite distinct from that of *Bact. coli*. On the special media, these features are accentuated and readily distinguish this subgroup from *Bact. coli* (though not from certain members of the other subgroups). Thus, on MacConkey's agar, colonies are large, circular, convex, opaque and mucoid, and have a pale pink central zone which gradually merges into a translucent, white periphery. The colonies soon coalesce but the general appearance of the growth remains the same, except for the pink colour which in the course of a few days gradually changes to a brownish-yellow hue. On methylene-blue-eosin agar, the colonies, which again tend to coalesce, are larger and lighter in colour than *Bact. coli* and lack the metallic sheen of the latter.

Biochemical Reactions. 1. *Fermentation* is accompanied by abundant production of gas (composed of CO_2 and H_2 in the ratio of 2 : 1) and a low acidity. Practically all the "sugars" in Table IV are fermented, the exceptions being inulin and dulcite in which no change usually occurs.

2. *Litmus milk*: the production of acid and clot is rapid.

3. *Indole* is not formed.

4. *Voges-Proskauer reaction*: positive.

5. *Methyl-red reaction*: negative.

6. *Citrate test* : positive.
7. *Utilisation of uric acid* : positive.
8. *44° C. test* : negative.

Pathogenicity. *Bact. aerogenes* is similar to *Bact. coli* in this respect, being essentially a saprophyte.

Viability. *Bact. aerogenes* and all the citrate-positive coliform bacteria are "hardier" organisms than *Bact. coli*. That they can outlive *Bact. coli* in water has already been mentioned. Their resistance to heat and disinfectants is, on the whole, also slightly greater. Thus, a water originally containing a mixture of coliform bacteria may, after inadequate sterilisation (*e.g.*, by chlorine, ozone, etc.), be freed from *Bact. coli* but still show the presence of *Bact. aerogenes*, *Bact. cloacæ*, etc.

Varieties of *Bact. aerogenes*, type I. The strains which MacConkey isolated and which may be said to belong to this subgroup are :—

- No. 103 (*B. lactis aerogenes*, *B. capsulatus* of Pfeiffer)—type species.
- No. 67, which differs from No. 103 by fermenting dulcitol.
- No. 75, which differs by fermenting dulcitol and not adonitol.
- No. 98, which differs by fermenting inulin.
- No. 104, (possibly) which gave an indefinite V-P reaction.

The differentiation of these individual strains is again of little service in water bacteriology. It may be of interest, however, to record that of this subgroup we find strains No. 67 and No. 75 to occur most commonly in water, and have isolated both from the same sample of well water.

6. *Bact. aerogenes*, type II

This subgroup, which is least often found in water, differs essentially from *Bact. aerogenes*, type I, in producing indole. Non-motility, encapsulation, and the development of mucoid colonies are again the rule, and the appearances on MacConkey agar are not significantly different from those of *aerogenes* I, though the central, coloured part of the colony is frequently red rather than pink and is more extensive, leaving a mere fringe uncoloured at the periphery. Gelatin is, however, sometimes liquefied (though this is not in accordance with the Ministry Table) and most strains display higher fermentative powers than those in any other subgroup. Thus, although gas production is not so abundant as with *aerogenes* I, all the "sugars" are fermented by MacConkey's type, No. 65 (*B. oxytocus perniciosus*) which may be regarded as the prototype of this subgroup, and the other strains usually ferment all but one of the "differential sugars," whilst inulin, which is seldom affected by the other subgroups, is here more often fermented than otherwise.

7. *Bact. cloacæ*

This subgroup, which is fundamentally distinguished from *Bact. aerogenes*, type I, only by the liquefaction of gelatin, derives its name from the "*B. cloacæ*" (1890) of Jordan, who found it to be very common

in sewage and described it as a motile coliform bacterium which usually produced indole. Quite a number of indole-positive strains do, in fact, occur, and would, in the Ministry Classification, be referred to *Bact. aerogenes*, type II, when they would seem to belong to this subgroup. The majority of cloacæ types, as isolated from water, however, lack the power of forming indole.

Most strains are motile and many are actively so. Capsule-formation is not infrequently present and colonies tend to become mucoid. Gelatin is liquefied, but seldom in less than a fortnight and sometimes only after six months. Non-mucoid colonies on MacConkey agar may closely resemble those of *Bact. coli*, type I, except that the periphery is whiter. The mucoid colonies, on the other hand, have quite a distinctive appearance which was first noticed by MacConkey. First of all, colourless, "watery," and often oval-shaped colonies develop, showing no sign of acid production. As the mucosity increases, however, and the colony becomes white and opaque, an eccentric spot of red makes its appearance in each colony and retains its sharp demarcation even after all the colonies have coalesced to form one confluent growth. The final picture is thus a whitish growth containing a number of distinct, circular, red spots each about 1 mm. in diameter.

Bact. cloacæ resembles *Bact. aerogenes* in being methyl-red-negative, Voges-Proskauer-positive, and citrate-positive, but differs in being frequently slow to produce clot in milk and gas in lactose. Though, in fermentation, it produces the same gas ratio as *aerogenes*, the quantity of gas is usually much less, and fewer "sugars" are affected. Thus, inositol, adonitol and dulcitol are seldom fermented and salicin is usually unaffected. Sucrose and raffinose are regularly fermented.

As regards viability, this organism is probably the most resistant in the whole coliform group; its properties in this respect will be discussed later.

8. The "Irregulars"

The reasons for difficulty in classifying the coliform bacteria will now be manifest. Needless to say, various investigators, notably Bergey (1939), have elaborated quite different schemes. Whatever efforts are made, however, there always remain a number of "anomalous" strains which cannot properly be included in any one of the subgroups and which in the Ministry Classification are conveniently described as "Irregulars." In the original differentiation of G. S. Wilson and his colleagues (1935), no less than eight different types of Irregular coliform organisms are described. The Ministry scheme, in abridging Wilson's list, grouped types 3-8 under "Irregular, other types—reactions variable" and specified only Irregular, types I and II. For the reasons already given, we prefer to include Irregular, types I and II with the corresponding types of *Bact. coli*, and we attach to the other Irregulars, on the few occasions they appear in water, the same significance as if they belonged to one or other of the ordinary citrate-positive types.

For convenience of reference, the main points of distinction of the standard subgroups are summarised in Table VII:—

TABLE VII

	Bact. coli.		Intermediate.		Bact. aerogenes.		Bact. cloacæ.
	Type I.	Type II.	Type I.	Type II.	Type I.	Type II.	
Motility . . .	+	±	+	—	—	—	++
Encapsulation . .	—	usy. —	—	+	+	+	often +
Mucoid colonies . .	—	" —	—	+	+	+	" +
Gelatin . . .	—	—	—	—	—	±	+
Growth in citrate .	—	—	+	+	+	+	+
Gas ratio, CO ₂ : H ₂ .	1 : 1	1 : 1	1 : 1	1 : 1	2 : 1	2 : 1	2 : 1
V-P reaction . . .	—	—	—	—	+	+	+
M-R reaction . . .	+	+	+	+	—	—	—
Indole production .	+	—	—	+	—	+	—
Uric acid utilisation	—	—	—	—	+	+	+
44° C. MacConkey test	+	—	—	—	—	—	—
Inositol . . .	—	—	—	+	+	+	—
Adonitol . . .	—	—	—	+	+	+	—
Sucrose . . .	±	±	±	+	+	+	+
Dulcitol . . .	+	+	±	±	—	+	—
Inulin . . .	—	—	—	—	—	+	—
Cellobiose . . .	—	—	+	+	+	+	+

Were it not for expense, fermentation of inositol might be included as an interesting extension of the routine tests. If the Intermediate organisms were then divided on the inositol reaction rather than on indole-production, two much better-defined types would result. It may also be noted that (with the exception of a few strains of Bact. cloacæ) it is the inositol-negative Intermediate which hampers the recognition of Bact. coli colonies on MacConkey agar. All other subgroups produce mucoid colonies as a general rule.

DISTRIBUTION OF THE COLIFORM BACTERIA

Since Escherich first described in 1885 the occurrence of "B. coli" in fæces, the abundance therein of such bacteria has been amply confirmed. That the term "B. coli," as then employed, covered a heterogeneous group of related organisms was soon, however, noted by Kruse (1894) who pointed out that certain varieties were also widely distributed in water and soil. In confirming the value of the gas ratio (CO₂ : H₂), Russell and Bassett (1899), showed that the high ratio (2 : 1) types appeared to be mainly normal soil forms rather than intestinal inhabitants, and by 1907 Winslow and Walker had come to the conclusion that, while B. coli communis and B. coli communior were essentially intestinal organisms, B. aerogenes types were more frequently found in soil and vegetation.

The first comprehensive classification to be attempted was that of MacConkey (1905, 1909) who obtained coliform bacteria from the fæces of man and numerous animals, and from soil, water, cereals and other foodstuffs. His definition of individual strains (to which reference has already been made) has not up to the present been surpassed, but, at that time, the value of the Voges-Proskauer reaction and its close correlation with the gas ratio were not realised. Having defined his strains, MacConkey then "arbitrarily" grouped them together, irrespective of the Voges-Proskauer reaction and solely according to the fermentative action on sucrose and dulcitol. He thus obtained the following "groups":—

Group.	Sucrose.	Dulcitol.	Represented by.
(1)	—	—	<i>B. acidilactici</i> .
(2)	—	+	<i>B. coli communis</i> .
(3)	+	+	(<i>B. coli communior</i> .)
(4)	+	—	<i>B. lactis aerogenes</i> .

and proceeded to quote the percentages of each such group which occurred in human and animal fæces, etc. As, however, each group contains members of what are now regarded as *Bact. coli*, together with members of the other subgroups, the figures obtained by MacConkey, and those who followed his example, are apt to be misleading. By rearranging his strains into the modern subgroups, the value of his work becomes more apparent (see Table VIII).

TABLE VIII
COLIFORM BACTERIA ISOLATED BY MACCONKEY FROM VARIOUS SOURCES
(Adapted from MacConkey, 1909)

Source.	Bact. coli.		Intermediate.		Bact. aerogenes.		Bact. cloacæ.	Total.
	Type I.	Type II.	Type I.	Type II.	Type I.	Type II.		
Human fæces	160	4	2	1	9	2	0	178
Animal fæces	145	0	1	0	2	0	6	154
Sewage	5	0	0	0	1	0	0	6
Water	11	2	1	4	2	0	29	49
Soil	10	1	0	0	0	4	1	16
Cereals, etc.	24	5	10	0	6	3	23	71

The striking preponderance of *Bact. coli*, type I, in fæces (almost 92 per cent.) is at once observed. If sewage had been more extensively examined, a somewhat similar result would doubtless have been obtained. From the other sites, about whose liability to fæcal pollution there is no information, 50 per cent. of the coliform organisms recovered were Voges-Proskauer-positive strains and less than 40 per cent. were *Bact. coli* types.

Clemesha (1912), working in India, studied the coliform flora of

human and bovine faeces, adopting for the sake of comparison the classification and "groups" of MacConkey. The details he supplied, while not allowing quite as complete interpolation as in the case of MacConkey, do permit recognition of the main subgroups, and the results of both investigators are on this basis compared in Table IX. As regards human faeces, the close similarity in the percentage distribution of the subgroups is remarkable.

TABLE IX
THE COLIFORM FLORA OF FÆCES
(Adapted from MacConkey, 1909; and Clemesha, 1912)

	Fæces.			
	Human.		Animal.	Cow.
	MacConkey.	Clemesha.	MacConkey.	Clemesha.
Bact. coli, types I and II .	92.1%	93.5%	94.1%	83.8%
Intermediate, types I and II .	1.7%	1.2%	0.7%	2.9%
Bact. aerogenes, types I and II .	6.2%	4.5%	1.3%	6.8%
Bact. cloacæ .	—	0.8%	3.9%	6.7%
Total No. of Organisms .	178	1,207	154	1,029

The relative importance of the Voges-Proskauer reaction was appreciated in 1914, when Rogers and his co-workers established the correlation between it and the gas ratio, and Clark and Lubs (1915) devised the methyl-red test. Summarising the results of many workers, Levine (1921) obtained the following figures :—

TABLE X

Source.	No. of strains examined.	Bact. coli types. Per cent.	Bact. aerogenes types. Per cent.
Human faeces .	2,534	94.1	5.9
Animal faeces .	1,832	92.6	7.4
Fæces .	4,366	93.5	6.5
Soil, grains, etc.	1,141	13.5	86.5

The existence of Intermediate types became apparent when Koser (1923-1926) introduced his synthetic citrate medium. Making the now-accepted use of the methyl-red, Voges-Proskauer, and citrate tests, he examined a number of "soil strains" from fields subjected to different degrees of pollution and obtained the following results :—

TABLE XI
DISTRIBUTION OF COLIFORM BACTERIA IN SOIL
(Koser, 1926)

Source.	Number of strains.	Bact. coli types.		Intermediate types.		Bact. aerogenes types.	
		No.	Percent.	No.	Percent.	No.	Percent.
Highly polluted soil	33	21	63.6	1	3.0	11	33.3
Lightly or chance polluted soil	104	24	23.1	8	7.7	70	67.3

Malcolm (1938), using ordinary methods of isolation, investigated 459 colonies of coliform bacteria obtained from the faeces of cows, and his results may be expressed as follows :—

Bact. coli, type I	447	97 per cent.
Intermediate, type I	3	3 per cent.
Intermediate, type II	0	
Bact. aerogenes, type I	4	
Bact. aerogenes, type II	3	
Bact. cloacæ	2	
	459	

To inhibit the growth of Bact. coli in further cultures from bovine faeces, Malcolm used a brilliant green medium and thereby obtained 374 citrate-positive coliform bacteria in the following proportions :—

Intermediate, type I	62
Intermediate, type II	27
Bact. aerogenes, type I	124
Bact. aerogenes, type II	46
Bact. cloacæ	115
	374

From the foregoing it is evident that Bact. coli, type I, completely overshadows the other coliform bacteria in faeces, whereas the vast majority of coliform organisms found in natural soil and vegetation are not Bact. coli but give a positive citrate reaction. The importance of these facts in water bacteriology is fundamental.

Distribution in Faeces and the Intestine. While Bact. coli, type I, may properly be termed "faecal coli" (*cf.* Ministry Report No. 71), there is not the same justification for applying the term "non-faecal" to the other coliform types, for the presence of small numbers of these in the faeces of healthy men and animals has been shown to be the usual rule, and considerable deviations from the average may occur according to season, species, disease, etc., whereby the citrate-positive types may assume much larger proportions. Thus Clemesha, who made a study of seasonal variation, agreed with MacConkey that *B. lactis aerogenes* and *B. cloacæ* were usually sparse in human faeces, but showed that the latter organism sometimes became extraordinarily numerous in cowdung.

Earlier observers, in studying the coliform flora of the intestine, had reported the presence of much larger numbers of these organisms. Ford (1903), for example, found about 28 per cent. of 200 organisms isolated post-mortem from the human intestine to be of the *B. lactis aerogenes* type, and Heinick (1903) found that in the intestines of pigs the number of *B. lactis aerogenes* was almost equal to that of *B. coli*. It does not, of course, follow that the proportions present in the faeces are necessarily the same as those in the intestine, but some similarity might be expected. Intestinal disease usually upsets the normal flora, and we have not infrequently found the faeces of patients suffering from gastro-enteritis or diarrhoea to yield, on direct plating, an almost pure culture of *Bact. aerogenes*.

Though individual variations do occur, the collective average in faeces remains remarkably constant, citrate-positive strains seldom approaching 10 per cent. of the total number present. Of these, the *Bact. aerogenes* subgroup is the only one which usually attains a significant percentage in human faeces, *Bact. cloacæ* being more prominent in animal faeces. The Intermediate types, of which type II is much less common than type I, do not figure appreciably in faeces and might without sensible error be termed "non-fæcal" organisms.

Distribution in Soil, Vegetation, etc. Since human and animal excrement is constantly being distributed over the inhabited parts of the earth's surface, it necessarily follows that the organisms contained therein are being still more widely disseminated. It is a matter of no surprise, therefore, that coliform bacteria can be found in air, soil, vegetation and water. Bacteria, as with other forms of life, are subject to the rule of the "survival of the fittest," and, in order to survive, they must overcome many hostile factors. These may be other bacteria, higher forms of life such as protozoa, or adverse conditions of dryness, temperature, sunshine or nutrition.

The distribution in nature of the coliform bacteria is thus dependent on the ability with which the respective types can adapt themselves to the altered circumstances they meet. *Bact. coli*, type I, is unable to withstand extra-intestinal conditions for long, and, although it may survive for some weeks in soil, water, etc., it does not flourish but becomes progressively less numerous and ultimately disappears. The same, however, is not equally true of the other coliform bacteria, some of which can apparently continue their existence outside the body for an almost indefinite period and can certainly long outlive *fæcal coli*, thereby causing the reversed proportions shown in Tables X and XI.

Methyl-red-negative Types. Clemesha was one of the earliest workers to investigate the resistance of the coliform bacteria, and found that, whilst *B. coli* was rapidly destroyed under the conditions of Indian sunshine, *B. lactis aerogenes* and *B. cloacæ* had greater powers of resistance, the latter to a marked degree. The remarkable viability of the Voges-Proskauer-positive types was again demonstrated by Wood (1918) and Savage (1918) who found experimentally that these bacteria could live for over three years in hard water which had previously been

heated. We had come to the same conclusions as the result of our own experience, several examples of which are recorded herewith :—

1. For many years past, bacteriological examinations made by us on samples of water from a number of deep boreholes have persistently shown the presence in varying numbers, often relatively large, of methyl-red-negative (*i.e.*, Voges-Proskauer-positive) coliform bacteria. *Bact. coli*, streptococci and *Cl. welchii* were never found, the chemical analysis remained constant and without exception showed the waters to be of high organic purity, and the most thorough investigations failed to demonstrate any possibility of adjacent pollution. The bore-tubes pass through several hundred feet of London Clay, and the outcrop of the Chalk from which the water is derived is miles distant. We, therefore, regarded these bacteria as of a resistant nature, able to subsist in underground water, and rejected them as indicators of near or significant contamination, or, alternatively, as derived from innocent sources. In this connection it is noteworthy that we have frequently found the packing of pumps to be laden with these types of bacteria.

2. The same state of affairs was encountered by one of us, during the war of 1914–18, with several similar borehole waters in the north of France, and Wood (1919) records further examples in a number of deep well waters obtained from the Limestone.

3. During an investigation, extending over several years, of a public water supply (a hard sand-filtered Chalk water in the south of England), it was found that the water in the service reservoirs contained methyl-red-negative coliform bacteria in appreciable numbers, whereas the water entering these reservoirs was usually free therefrom or showed the presence of only very small numbers. The reservoirs were efficiently covered and protected and it was concluded that the bacteria were multiplying therein. Experiments carried out on the wet sand from the filter beds showed that, when the sand was stored in bottles at room temperature, multiplication of these bacteria took place and they could be isolated from it for at least nine months afterwards.

4. In the case of another sand-filtration works, the presence of *Bact. aerogenes* became apparent in the filtered water. Examination of the sand beds showed a large and unusual algal growth in association with large numbers of *Bact. aerogenes*. This growth (*Enteromorpha intestinalis*), when kept in water in the laboratory, favoured the multiplication of these bacteria to a remarkable degree.

We could give many more instances of the multiplication of the methyl-red-negative coliforms in stored water, but enough has been said to show that the presence in water of these types is of less significance than similar numbers of *Bact. coli*.

Clemesha pointed out that multiplication of *B. lactis aerogenes* was a phase in water purification, an observation with which we agree.

The water supply, mentioned in Paragraph (3) above, is subject to periodic pollution by heavy rains. At such times the total bacteria are markedly increased and *Bact. coli*, accompanied by other coliform organisms, appears in fair numbers. With the cessation of rain, the originally predominant *Bact. coli* rapidly disappears but the *Bact. aerogenes* types become numerically superior and persist for some considerable time before showing any reduction of their numbers. It is more than probable that the rapid disappearance of *Bact. coli* is largely due to the presence of the other coliform bacteria.

Intermediate Types. Since the introduction of the citrate test enabled recognition of the Intermediate coliform bacteria their behaviour has been found to be substantially similar to that of *Bact. aerogenes*. Thus we could quote instances, similar to those above-mentioned, in which Intermediate, type I, played the same part as *Bact. aerogenes*. Intermediate, type II, though it does occur in soil, is almost as uncommon in water as in faeces, and those strains (*i.e.*, the inositol-negative ones) which most closely resemble *Bact. coli*, type I, are seldom found anywhere. On the other hand, Intermediate, type I, though not usually as common as *Bact. aerogenes* in soil, is quite frequently found in water (see Table XIII).

Summary. As compared with *Bact. coli*, the preponderance of the citrate-positive types in soils, etc., which seem remote from any possible faecal pollution has been indicated in Tables X and XI. Their higher powers of resistance have also been discussed. Their presence in water, in the absence of *Bact. coli*, is usually, therefore, considered of less importance than similar numbers of *Bact. coli*. To regard them, however, as of no significance would be unwise, for while the absence of *Bact. coli* may be said to exclude recent pollution, the presence of these bacteria might disclose a hitherto unsuspected possibility of pollution, neglect of which might be followed by serious consequences. The only safe procedure, therefore, is to regard all true coliform bacteria as of potentially dangerous origin until, or unless, subsequent investigation into the source and history of the water can explain their presence to be due to relatively innocent causes. In this latter connection, we have already mentioned the pump packing as an occasional source of lactose-fermenters. The same may be said of leather washers, and the hemp and other materials used in the jointing of water mains.

EXAMINATION OF WATER FOR BACT. COLI

The reliability of this examination, as in the case of the total bacteria counts, depends on the care exercised in the process of sampling, a point which cannot be too often emphasised. Sampling has already been discussed in Chapter XV, and failure to adhere rigidly to the rules there laid down may rob the examination of its great value. Here, also, the necessity for scrupulous cleanliness and sterility in the sampling bottles applies particularly, and the most careful laboratory technique must be observed.

Although *Bact. coli* is the principal object of search in this examination, the other coliform bacteria are not so unimportant that their presence in water can be entirely neglected. For this reason the "rapid" methods, suggested in recent years, which purport to enumerate faecal *Bact. coli* directly and provide no information, or little that is reliable, about the other members of the coliform group, are of limited value. These will be described later, but for routine purposes we still

retain the standard method whereby the presence and approximate number of coliform bacteria are first indicated, and the various types thereafter isolated and differentiated.

Approximate Enumeration of the Coliform Bacteria (with Subsequent Identification of *Bact. coli*)

In Chapter XXVII it was shown how a rough estimate of the coliform content of certain waters could be obtained by direct plating on neutral-red bile-salt lactose agar. The use of a solid medium for the primary inoculations has only a restricted value, however, for the following reasons:—

1. Only small quantities of water (*e.g.*, up to 5 c.c.) can be incorporated in the usual plate (unless resort is had to concentration methods which are tedious and introduce complications and errors). A single plate might, therefore, confirm the impurity of a heavily polluted water, but to establish the purity of a drinking water (which should preferably contain no coliform bacteria in 100 c.c.), a minimum of twenty plates would be required.

2. The bacterial flora of water is a mixed one, and the red colonies developing on the plate represent not only coliform bacteria, but also any micro-organism which can merely produce acid from lactose.

3. Recognition, with reasonable certainty, of surface colonies of *Bact. coli*, though difficult, is possible after much experience with MacConkey agar; but this method results in the development also of "deep" (*i.e.*, buried) colonies which cannot be distinguished by naked-eye appearances. Hence, to obtain the proportion of *Bact. coli* present would involve subcultivating each of the red colonies, followed by the usual confirmatory and differential tests, and so laborious a task is impracticable for routine work.

4. Experience has shown that primary cultivation on a solid medium does not encourage the growth of those strains of *Bact. coli* which have become attenuated by exposure to adverse conditions, as pertain in water. The true coli count (as opposed to red colonies) tends, therefore, to be somewhat lower than when the liquid medium is used.

The above difficulties are largely overcome by employing a liquid medium and the "dilution method" of counting. The first step, in this case, is to find the smallest quantity of water which appears to contain coliform bacteria, or to prove the absence of the latter from a given quantity, say 100 c.c.

1. *Presumptive Coliform Test.* As with other determinations in water analysis, the sample bottle, before being opened, is well shaken to ensure that all portions of the contents are reasonably representative of the whole. Varying quantities of the sample are then added to bile-salt lactose peptone solution (loosely called "MacConkey Broth") and the mixtures incubated at 37° C. The production of acid and gas within forty-eight hours constitutes a "presumptive coliform reaction," the term "presumptive" being used because some other bacteria besides the true coliform group are also capable of giving this reaction. These "false presumptive" results may be caused by the following agencies:—

1. Gram-positive, spore-bearing, anaerobic bacilli.
2. Gram-positive, non-sporing bacteria (*e.g.*, *Lactobacillus*).
3. Micrococci, yeasts and fungi.
4. A mixture of organisms, no one of which, growing alone, can produce this change.

These organisms are, however, appreciably inhibited by the bile-salt present in the medium, and usually show slow and little gas production with often only a slight acidity. The need for bile-salt in the medium was emphasised by the results obtained by American workers who, using a simple lactose broth, obtained unusually numerous false presumptive reactions. Where the bile-salt is of good quality, and the observer experienced, the proportion of accepted presumptive reactions which later prove to be false is, in this country, only 5 to 10 per cent., depending on the character of the waters examined.

There are few natural waters, however pure, from which coliform bacteria, and indeed *Bact. coli*, could not be isolated if large enough quantities of water were taken and examined sufficiently often, hence it becomes necessary to restrict the examination to an agreed volume of water. It is now standard practice to examine approximately 100 c.c. in the case of all reasonably pure waters such as are likely to be consumed. Larger amounts than this are employed in special cases, *e.g.*, when processes of purification are being investigated and exact comparisons made. On the other hand, smaller quantities often suffice, as in the examination of polluted waters, sewage effluents, etc.

The amount of water selected for examination is divided and distributed in varying amounts into sterilised flasks or culture bottles and tubes of the medium, the procedure to be adopted depending on the suspected bacterial impurity of the water. Thus the quantities distributed may be :—

Series A. For waters which are expected to be of the highest standard of purity and to give a "Negative in 100 c.c." result, as should generally be the case in public water supplies : one of 50 c.c. and five of 10 c.c.

Series B. For waters which are unknown, but are probably of satisfactory quality : one of 50 c.c., five of 10 c.c. and five of 1 c.c.

Series C. For waters known or expected to be of inferior quality, but not highly polluted : five each of 10 c.c., 1 c.c. and 0.1 c.c.

Series D. For waters known to be polluted. This varies according to circumstances. Thus a common series for English river waters is one of 10 c.c., and five each of 1 c.c., 0.1 c.c., 0.01 c.c. and 0.001 c.c., but larger or smaller quantities may be employed.

The object is to cover a sufficiently wide range to obtain both positive and negative results, and to have five tubes at or about the critical level. The selection depends largely on experience and discretion, and manifestly no fixed series will suit all cases without great waste of material and labour.

The medium used for the primary cultures is designed (1) to favour the growth of coliform bacteria, especially *Bact. coli*, and at the same time inhibit the growth of other organisms; (2) to demonstrate

to the naked eye the probable presence or absence of coliform bacteria. Various media have been employed for this purpose, but the medium introduced in 1901 by MacConkey and Hill, with certain modifications, is still, in our experience, the best. It is the one we invariably employ and consists of bile-salt lactose peptone solution to which litmus or neutral-red is added as indicator (see Appendix). It is prepared in various concentrations, so that the final dilutions obtained by adding the varying quantities of water are of the same strength. The medium is sterilised in flasks or culture bottles and tubes of various sizes, each containing a small inverted (Durham) tube for the demonstration of gas production.

The water is added by sterile pipettes to the tubes of medium, quantities of water under 1 c.c. being arranged by preparing dilutions with sterile water, as described in the previous chapter (see p. 428). The tubes thus inoculated are incubated at 37° C. (preferably after warming to temperature), and inspected after twenty to twenty-four and forty-eight hours.¹ In that time, one of the following results will be observed :—

1. No change, or turbidity only.
2. Production of turbidity and acidity, but no gas.
3. Production of turbidity with acid and gas.

If, at the end of forty-eight hours' incubation, results 1 and 2 are recorded, the water can be considered free from coliform bacteria in the quantities examined, and the tubes may be discarded (unless some other special examination is required). Result 3 indicates that coliform bacteria may be present, but before this is accepted as a "presumptive reaction" a sufficient amount of gas must have been produced to fill at least the concavity of the Durham tube. By this selection a fair number of the spurious results are dismissed. The slow gas production of the non-coliform organisms has already been mentioned. On the other hand, *Bact. coli* seldom fails to fill at least one-fifth of the Durham tube with gas and usually does so within twenty-four hours. Many of the other coliform bacteria produce much more gas though they often take longer to do so, but a number (of the Intermediates, especially) produce only the minimal quantity in the forty-eight hours. From tubes showing active gas production in twenty to twenty-four hours, it may be stated that *fæcal Bact. coli* will ultimately be isolated in at least 80 per cent. of cases (see Table XIII, p. 477).

It should be noted, however, with reference to the rapidity of fermentation, that great care is essential in the preparation of the medium and much depends on the quality of the peptone. A badly prepared medium or an inferior brand of peptone may result in delayed activity with consequent loss in gas production, and an excess of indicator may have similar results. Moreover, the presence in the

¹ Inspection may, with advantage, be commenced from twelve hours onwards and subcultures should be made as soon as the presumptive reaction is observed.

water of an excess of metals, *e.g.*, iron, copper, or zinc and an unusual acidity or alkalinity may retard or inhibit growth.

2. *Isolation of the Coliform Bacteria.* The preliminary presumptive findings having been recorded, the next step consists in isolating the various coliform bacteria in pure culture to permit the third stage, *i.e.*, application of the confirmatory and differential tests. From the positive presumptive tubes, subcultures are made as early as possible on to one of the differential solid media, *e.g.*, Endo's, eosin-methylene-blue agar, or MacConkey agar. All are valuable but the last-named has our preference and is extensively used.

Plates of the medium are first prepared. After the medium has set, the plates are dried for an hour in the 37° C. incubator, the cover resting on the edge of the inner dish which contains the medium. From each presumptive tube, a small inoculum on a straight platinum wire is transferred to a plate and evenly spread over the surface by a sterile glass spreader. The inoculum may, if preferred, be mixed in 0.5 c.c. of sterile diluent and a loopful of the dilution transferred to the plate.

It is not always practicable or necessary to plate out all the presumptive tubes, but a reasonable number and a representative selection can be arranged. A considerable economy can be effected when necessary by ruling off each plate into three sectors. Three such plates will then serve for nine tubes and are usually sufficient for most samples. The lowest dilutions showing the presumptive reaction must, of course, be included, and any tubes not subcultured must be retained for examination in the event of failure with the preceding ones. It is obviously better to plate out too many of the tubes than too few.

The inoculated plates are inverted (closed) in the 37° C. incubator. After twenty-four hours or less they are removed for inspection. Discrete and well separated colonies should be obtained if the inoculum has been small enough and the spreading properly performed. The various coliform colonies, whose appearances have already been described, can often be recognised, but the first question to decide is whether each subculture has resulted in the growth of red, coliform-like colonies, *i.e.*, to confirm, as far as possible at this stage, the presumption that the primary tubes contained coliform bacteria.

In some few cases, the surface of the medium is devoid of colonies of any kind, the conclusion being that the presumptive reaction was false and due to obligatory anaerobes. Similarly, only white or non-lactose-fermenting colonies may have appeared, in which case a further false presumption is disclosed, that due to a mixture of species in the primary tube effecting what no one of them could do in pure culture. The same conclusion follows when, either alone or associated only with white colonies, the red, pin-point colonies of bile-tolerant cocci (enterococci or faecal streptococci) are seen. Unless these last-named organisms are being investigated as part of the general bacteriological examination (when such plates could be retained), all the above plates are discarded once the findings have been recorded.

Most commonly, however, coliform colonies appear on all plates, with perhaps a few white colonies intermingled. Frequently, and especially in the lower dilutions, the characteristic colonies of *Bact. coli* are seen in almost pure culture, but a mixture of several coliform types is not at all uncommon. In those cases where another coliform type, e.g., *Bact. aerogenes*, is in the ascendancy, the lower dilutions may tend to show nothing but that organism.

Each plate and sector is, therefore, carefully scrutinised for the presence of possible *Bact. coli* colonies. In many cases, the certainty of the latter to the experienced eye is sufficient to render subsequent confirmation little more than a formality—a procedure which, however, should not be omitted. From each sector, two or three *coli* colonies, or those most nearly similar, are selected for the application of the confirmatory tests. The process is designed throughout to demonstrate the presence of *Bact. coli*, and, in the absence of this organism, attention is turned to the other coliform types. No effort is made, even if it were possible, to show the proportion of each coliform type originally occurring in the sample.

3. *Differentiation of Bact. coli*. It is manifestly impracticable in routine work to apply all the various differentiating tests of *Bact. coli*, and only the four detailed on p. 452 are employed, as being considered at present the essential minimum.

The selected colonies are picked off with a straight platinum wire and inoculated (*via*, if desired, a peptone water solution, as described in the citrate test) into the following:—

1. MacConkey lactose broth, for confirmatory lactose fermentation with production of acid and gas at 37° C., and, if possible, at 44° C.
2. Koser citrate medium.
3. Glucose phosphate peptone solution, for the methyl-red test, and also, if desired, the Voges-Proskauer test.
4. Peptone water, for production of indole.

The morphology (and motility) of the organism can be conveniently observed by making preparations from the growths in 3 and 4. Further tests may be added, should they be considered necessary.

All the inoculated tubes are incubated at 37° C. Of the coliform bacteria, now present in pure culture, the great majority give a positive lactose-fermentation test within twenty-four hours, and *Bact. coli* seldom fails to do so in that time. Tubes failing to show sufficient gas after twenty-four hours are re-incubated for a further twenty-four hours. A negative result, now, compels the rejection of the selected colony from the coliform group, and for practical purposes, is regarded as disproving the original presumption. It is extremely uncommon for properly selected colonies to fail on morphological grounds.

The performance of the differential tests has already been described (p. 449), but where time presses, certain modifications are permissible. The citrate test can usually be read after only twenty-four hours, and a preliminary test for indole production can also be made in that time, if duplicate tubes were inoculated. Moreover, with the exception

of those few cases where it is essential accurately to distinguish between coliform types other than *Bact. coli*, the methyl-red test can also be performed after twenty-four hours' incubation, for that time is ample for *Bact. coli* to give a positive reaction, and the only difficulty is that the aerogenes-cloacæ types may not yet have regained neutrality and would, therefore, be wrongly recorded as (methyl-red-positive) *Intermediates*. Even this seldom occurs in practice, however, but in cases where the identification of *Bact. coli* with all speed is particularly desirable, the accurate *differentiation* between the other coliforms is not sufficiently important to be worth delaying the result.

Summary. The time factor is held up as a disadvantage of this method, but this criticism has little foundation in practice. We have already said that most strains of *Bact. coli* give the presumptive reaction in twenty-four hours, and reference to Table XIII, p. 478, shows that only 10·8 per cent. of 7,139 strains required a longer time. Actually, the more rapidly the acid and gas develop, the more likely is *Bact. coli* to be present, and experience has shown that the sooner the first appearance of gas in the fermentation tubes is followed by sub-culture, the purer are the subsequent cultures of *Bact. coli*. For rapid work, platings can be successfully made after twelve hours from tubes which show early acid production, and even before the appearance of gas (the tube being, of course, retained in the incubator for demonstration of the presumptive reaction in the usual time). Thus, within twenty-four hours of the receipt of a sample, it is possible to say whether a water is seriously polluted or not, and in forty-eight hours the majority of *Bact. coli* present can be isolated on the MacConkey agar where they are recognisable with reasonable certainty by the experienced worker. The presumptive test is also completed in that time. As will be shown later, there is no other method which provides more information in so short a time. The misapprehension regarding the delay of this method arises from considering, without regard to actual practice, the maximum period required for each stage, thus :—

Presumptive Coliform Test	2 days.
Isolation of colonies	1 day.
Differential tests	2-5 days (7 days where an attempt is made to obtain gelatin liquefaction).
Total	5-10 days.

While such conditions apply in deliberate research, the delays involved need play little part in practical water bacteriology or water-works control. For example, the production of acid and gas in the MacConkey tubes within twenty-four hours of incubation at 37° C. is a significant finding in any final water intended for public supply purposes, and justifies immediate inquiry. Such positive results may, in fact, be observed only after twelve to fifteen hours' incubation, and, in the majority of instances, they prove to be due to *Bact. coli*. When the available facilities permit the duplication of the primary MacConkey tubes, one set being incubated at 37° C. and the other at 44° C., the

appearance of positive results in both sets provides a still stronger probability of the presence of *Bact. coli*, and, accordingly, of potentially dangerous contamination. Although further examination of the primary MacConkey cultures should be carried out in order to confirm the strong presumptive evidence already obtained, there should be no delay in initiating waterworks investigations and taking appropriate precautions pending the confirmatory laboratory tests and verification of the reliability of the original sample of water. Since growth of most strains of coliform bacteria is inhibited by incubation at 44° C., and some of these are of sanitary importance, the 37° C. cultures should be examined. Differential tests subsequently applied to isolated cultures can be restricted to four in number without serious omission. The occurrence of false presumptive reactions, particularly after two days' incubation, should not be overlooked.

Analysis of Results obtained by Differentiation

In an attempt to assess the value of the confirmatory lactose-fermentation test, we recently tabulated the findings arising from 10,000 consecutive presumptive coliform reactions obtained from samples of water subjected to routine bacteriological examination. No deviation from normal technique was involved, the analysis being compiled from the ordinary laboratory records and including results obtained from many varieties of water, irrespective of source, treatment, etc. The number of samples contributing to these results was considered irrelevant and is not, therefore, recorded. The findings are set out in Table XIII which illustrates many interesting facts in addition to those originally sought.

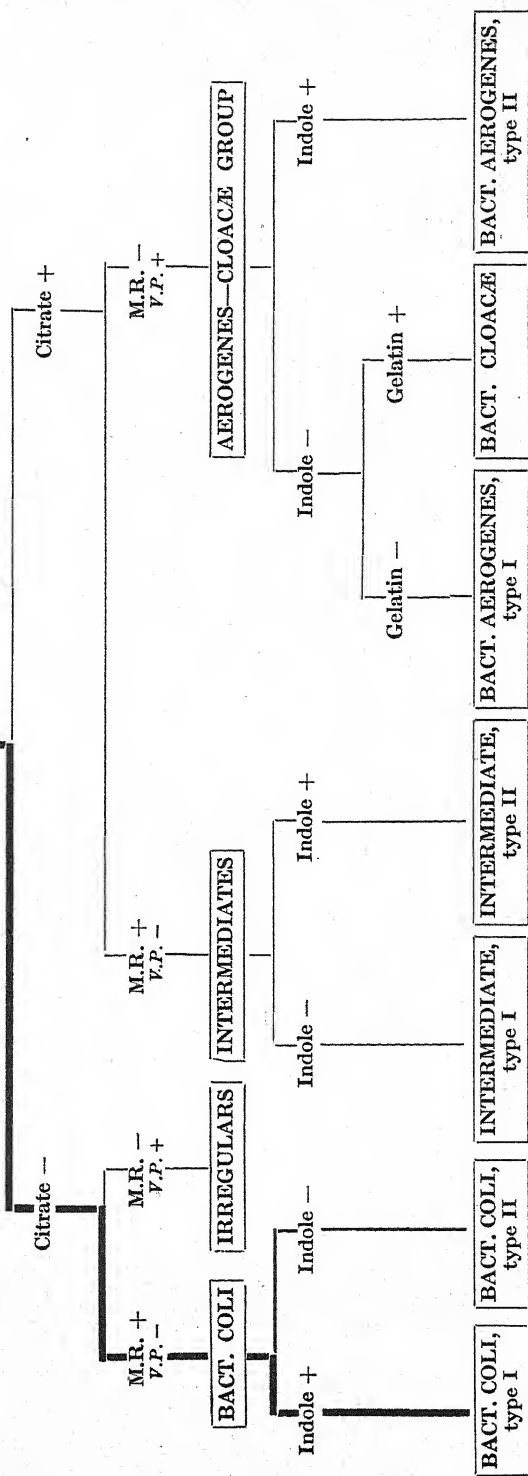
The presumptive reactions are listed in Section "A" where it can be seen that, of the total 10,000, 7,645 occurred within twenty-four hours and 2,355 required longer incubation. The false reactions excluded on colonial appearances are shown at the foot of this section, whilst Section "B" indicates presumptive reactions resulting in "coliform" colonies which separately satisfied all the differential tests, but failed to produce gas from lactose. From the third section, headed "A-B," all spurious results have been excluded and the true coliform bacteria are listed in their various subgroups.

The figures in no way represent the relative distribution of coliform bacteria in water, but are merely an expression of the success or otherwise of the search for *Bact. coli*. Thus, wherever *Bact. coli* was isolated, the presence of other coliform types in the same quantum was neglected.

Perhaps the most noteworthy features in Section "A" are the small proportion of "first-day" presumptive reactions (1.6 per cent.) which failed to yield "coliform" colonies, and the high proportion (over 83 per cent.) from which *Bact. coli*, type I, was ultimately isolated. In comparison, the "second-day" presumptive reactions, though relatively much less numerous, gave a greater actual number (362) and proportion (15.3 per cent.) of colonial failures and a much smaller yield of *Bact. coli*, type I. The reliability of the first-day presumptives is still further enhanced when it is noted that of 7,527

TABLE XII
DIFFERENTIATION OF COLIFORM BACTERIA
ISOLATED COLONIES OF
BILE-TOLERANT, GRAM-NEGATIVE, NON-SPORING, ROD-SHAPED BACTERIA

LACTOSE + (A. & G.).



Note : Coliform bacteria (belonging to the Irregular subgroup) which give M.R. + V.P. + or M.R. - V.P. - reactions are not represented in the above scheme as they are of very infrequent occurrence.

TABLE XIII

RESULTS OF DIFFERENTIATING 10,000 PRESUMPTIVE COLIFORM REACTIONS OBTAINED DURING ROUTINE BACTERIOLOGICAL EXAMINATION OF SAMPLES OF WATER

DIFFERENTIAL CLASSIFICATION		A						B						A-B					
		PRESUMPTIVE COLIFORM REACTIONS (Acid and sufficient gas in MacConkey Broth at 37° C.)						"NON-LACTOSE-FERMENTERS" RESULTING FROM "A" (Gas not produced by pure cultures in MacConkey Broth, 37° C.)						TRUE COLIFORM BACTERIA					
		1ST DAY		2ND DAY		TOTAL		1ST DAY		2ND DAY		TOTAL		1ST DAY		2ND DAY		TOTAL	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
TRUE PRESUMPTIVE COLIFORM REACTIONS (Confirmed on Colony Appearance)	Bact. coli, type I	6,369	83.3	770	32.7	7,139	71.4	1	0.016	15	2.0	16	0.2	6,368	86.0	755	43.8	7,123	78.0
	Bact. coli, type II	229	3.0	255	10.8	484	4.8	41	17.8	86	33.7	127	26.2	188	2.5	169	9.8	357	3.9
	Intermediate, type I	416	5.4	504	21.5	920	9.2	44	10.6	75	14.9	119	12.9	372	5.0	429	24.9	801	8.8
	Intermediate, type II	138	1.8	118	5.0	256	2.6	7	5.4	7	5.9	14	5.5	131	1.7	111	6.4	242	2.6
	Bact. aerogenes, type I (and Bact. cloacae)	300	3.9	247	10.5	547	5.5	9	0.3	33	13.4	42	7.7	291	3.9	214	12.4	505	5.5
	Bact. aerogenes, type II	42	0.6	41	1.7	83	0.8	1	2.4	4	9.7	5	6.0	41	0.6	37	2.2	78	0.9
	Irregulars	33	0.4	58	2.5	91	0.9	12	36.4	50	86.2	62	68.2	21	0.3	8	0.5	29	0.3
	TOTALS	7,527	98.4	1,993	84.7	9,520	95.2	115	1.5	270	13.5	385	4.0	7,412	100.0	1,723	100.0	9,135	100.0
COLIFORM REACTIONS FALSE PRESUMPTIVE	"White Colonies," and "Cocci"	73	1.0	274	11.6	347	3.5	Notes: (1) The columns headed "1st Day" and "2nd Day" refer in all cases to the original presumptive coliform reactions. Thus, presumptive reactions appearing within 24 hours and the organisms isolated therefrom are found in the "1st Day" columns. (2) The percentages in Section "B" are obtained by comparing the adjacent number with the corresponding number in Section "A." All other percentages are based on the total at the foot of the column.											
	"Anaerobes"	45	0.6	88	3.7	133	1.3												
	TOTALS	7,645	100.0	2,355	100.0	10,000	100.0												

colonial successes only 115 (or 1.5 per cent.) failed on the confirmatory lactose test, whereas 1,993 second-day presumptives, which yielded coliform colonies, produced 270 (or 13.5 per cent.) "non-lactose-fermenters."

The need for the confirmatory lactose test is therefore established, especially in the case of delayed presumptive reactions. By this test, a total of 4 per cent. of "colony-confirmed" presumptive reactions were excluded. Note, however, that only one non-lactose-fermenter was obtained from 6,369 early presumptive reactions which yielded colonies satisfying the differential tests of Bact. coli, type I, and contrast this with the high proportion (86.2 per cent.) of non-lactose-fermenting colonies giving Irregular results and coming from delayed presumptive reactions.

In Section "A-B" the proportions obtained of each coliform type are to be accepted with reserve, as they must necessarily be dependent upon the types of waters examined and upon the experience of the observer. We have found, however, that the figures shown in this section are subject to comparatively little deviation in practice. They may, therefore, be regarded as useful indicators of the relative frequency with which the various sub-groups are found during the search for *Bact. coli*. The close similarity between some of the Intermediate colonies and those of *Bact. coli* is reflected in the comparatively high proportions (8.8 and 2.6 per cent.) of these types in the final column. *Bact. aerogenes*, types I and II, and *Bact. cloacæ*, being more easily distinguished from *coli* colonies, are recovered only from plates showing no apparent *Bact. coli* and thus seem to occur less frequently. Note how the confirmatory lactose test removes the great majority of the Irregulars.

The conclusions which may reasonably be drawn from the above survey are as follows:—

1. First-day presumptive reactions may be regarded as 97 per cent. "true," and as containing at least 80 per cent. of *Bact. coli*, type I. If *Bact. coli* were the only coliform bacterium of significance, interpretation could be based largely on first-day presumptive reactions, but the error would be on the wrong side for safety.

2. As the other coliform bacteria are not necessarily devoid of importance, however, the second-day presumptive reactions, which comprise about one-quarter of the total and are largely due to citrate-positive coliforms, must be considered. Here, the much greater frequency of spurious reactions renders confirmation a necessary preliminary to interpretation.

Expression of Results

While the ultimate object of the examination is to find the smallest quantity of water from which *Bact. coli* can be isolated, much useful information may be obtained by judicious consideration of the presumptive coliform reactions. Where these are all negative, the absence of *Bact. coli* from the quantity of water examined is already established, but in cultures showing acid and sufficient gas, *Bact. coli* is probably, and coliform bacteria very probably, present.

In such cases, the result is, in our opinion, adequately expressed in terms of the smallest quantity of water giving rise to the presumptive reaction, together with the largest quantity of water failing to do so. Thus, where in a series all of five 1 c.c. tubes are "positive" and all five 0.1 c.c. tubes are negative, the findings would be recorded: "Presumptive Coliform Reaction: present in 1 c.c., absent from 0.1 c.c." Results as clear-cut as this are frequently obtained with samples which are free from suspended matter, provided they have been properly shaken just prior to the commencement of the examination. Sometimes, however, all the tubes of a particular volume do not show the same result, and the assessment must then be made on a majority basis. The theoretical inaccuracy of this procedure is permissible where small volumes, such as 1 c.c., show positive presumptive reactions, as there is usually little significant sanitary difference between a water giving

the results cited in the above example and one producing fermentation in only three of the five 1 c.c. tubes. Certainly, no water of this grade could be regarded as satisfactory for drinking and domestic purposes, and greater accuracy would be required only in comparative experiments, *e.g.*, to gauge the efficiency of a treatment process, where a larger number of tubes would have been inoculated. As, however, waters showing positive results only in the larger volumes may vary widely in their sanitary quality, it is advisable in such cases to return the results in the manner suggested in Table XIV, Column B.

TABLE XIV

EXPRESSION OF PRESUMPTIVE COLIFORM RESULTS

(Volumes of water inoculated : one of 50 c.c. and five each of 10 c.c. and 1 c.c.)

A Number of Tubes showing acid and gas.			B Presumptive Coliform Reaction.		C Presumptive Coliform Count.*
50 c.c.	10 c.c.	1 c.c.	Present in	Absent from	Per 100 c.c.
0	0	0	—	100 c.c.	0
0	1	0	100 c.c.	50 c.c.	1
1	0	0	100 c.c.	25 c.c.†	1 (2)
1	1	0	50 c.c.	25 c.c.†	3
1	2	0	25 c.c.†	10 c.c.	5 (6)
1	3	0	20 c.c.†	10 c.c.	8 (9)
1	4	0	10 c.c.	1 c.c.	13 (16)
1	5	0	10 c.c.	1 c.c.	25 (18+)
1	4	1	10 c.c.	1 c.c.	17
1	5	1	5 c.c.†	1 c.c.	35
1	5	2	5 c.c.†	1 c.c.	50
1	5	3	1 c.c.	0.1 c.c.	90
1	5	4	1 c.c.	0.1 c.c.	160
1	5	5	1 c.c.	—	180+

* *i.e.* the probable number of presumptive coliform bacteria (*see* p. 484).

† In routine work, results are generally recorded in terms of 100 c.c., 50 c.c., 10 c.c., 1 c.c., etc., intermediate values such as 25 c.c., 20 c.c. and 5 c.c. being reserved for special purposes.

With a reasonably clear water and good laboratory technique, variations apart from those indicated in the table are very rarely encountered. It will be noted that absolute precision is not attained (nor attempted), for long experience has shown this method to be adequate in demonstrating whether or not a water is suitably free from presumptive coliform bacteria (and, later, *Bact. coli*).

At the end of the examination, when the number of tubes yielding actual *Bact. coli* has been demonstrated, the critical quantities of water containing (and not containing) *Bact. coli* can be similarly expressed. Thus, a water inoculated into the series of tubes specified in Table XIV might give rise to presumptive reactions in the 50 c.c. and all the 10 c.c. tubes, but *Bact. coli* might be isolated from only the 50 c.c. and one of

the 10 c.c. volumes, the other presumptive reactions having been due to, say, Intermediate, type I. The results could then be summarised as follows :

"Presumptive Coliform Reaction : present in 10 c.c., absent from 1 c.c.

"Bact. coli : present in 50 c.c., absent from 10 c.c."

with a rider to the effect that "The other coliform bacteria present were found to be Intermediate, type I." Supposing, however, the four non-coli reactions had been shown to be false, the tabulated result would remain the same, but the rider would run : "The other presumptive reactions proved to be spurious and due to anaerobic bacteria, aerobic sporing bacteria, non-lactose-fermenting bacteria," according to what was found.

In view of the fact that the whole examination is subject to a certain degree of error, it would seem of doubtful value to strive after a greater degree of accuracy than is adequate for the purposes of interpretation. The virtue of the method recommended above is that, while fulfilling the latter condition, it conveys only that amount of precision which the examination justifies. For many years, however, increasing efforts have been made to devise a more accurate method of enumeration, and tables, based on the theory of probability, have been compiled whereby the *probable number* of Bact. coli present in a given quantity of water can be calculated from the number of the various tubes yielding that organism.

Buchanan and Fulmer (1928), following McCrady (1918) and applying this procedure to the dilution method of counting in general bacteriology, recommended that five samples of each dilution should, preferably, be used, but allowed a smaller number as sufficient where accuracy was less important. A sufficient number of decimal dilutions were to be used so that all (or most) of the tubes containing the highest dilutions would remain sterile. The dilutions might therefore comprise the following : x c.c., $0.1 x$ c.c., $0.01 x$ c.c., $0.001 x$ c.c., $0.0001 x$ c.c., and the results were to be recorded by placing in a series the numbers of positive results obtained in each set of dilutions. For example, assuming that five samples of each of five dilutions are tested, one might secure such a number as 55410 (which would indicate that all the tubes inoculated with x c.c. and $0.1 x$ c.c., four of the five tubes containing $0.01 x$ c.c., one of the five containing $0.001 x$ c.c. and none of the $0.0001 x$ c.c. tubes showed the desired result). The table being based on three significant figures, the significant number would be 541 in this case and could be defined in general as including the figure representing the highest dilution in which all the tubes are positive, together with the figures representing the next two dilutions. Where, however, the first dilution does not show all the tubes positive, the first three figures are significant, *e.g.*, in a result 33100 the significant number is 331 (whether 3, 4 or 5 samples of each dilution were used). Again, where four significant figures are obtained, as in 55321, the last figure is added to the preceding one, making in this case 55330 with 533 as the

TABLE XV

SHOWING PROBABLE NUMBER OF ORGANISMS WITH 2, 3, 4 AND 5
TUBES OF EACH DILUTION

(From Buchanan and Fulmer, after McCrady)

Number of Tubes of each Dilution.				Number of Tubes of each Dilution.			
2	3	4	5	2	3	4	5
Significant Numbers.				Probable Number of Organisms.			
001	001	001	001	0.5	0.3	0.2	0.2
010	010	002	002	0.5	0.3	0.5	0.4
011	011	003	010	0.9	0.6	0.7	0.2
020	020	010	011	0.9	0.6	0.2	0.4
100	100	011	012	0.6	0.4	0.5	0.6
101	101	012	020	1.2	0.7	0.7	0.4
110	102	013	021	1.3	1.1	0.9	0.6
111	110	020	030	2.0	0.7	0.5	0.6
120	111	021	100	2.0	1.1	0.7	0.2
121	120	022	101	3.0	1.1	0.9	0.4
200	121	030	102	2.5	1.5	0.7	0.6
201	130	031	103	5.0	1.6	0.9	0.8
210	200	040	110	6.0	0.9	0.9	0.4
211	201	041	111	13.0	1.4	1.2	0.6
212	202	100	112	20.0	2.0	0.3	0.8
220	210	101	120	25.0	1.5	0.5	0.6
221	211	102	121	70.0	2.0	0.8	0.8
222	212	103	122	110.0	3.0	1.0	1.0
—	220	110	130	—	2.0	0.5	0.8
—	221	111	131	—	3.0	0.8	1.0
—	222	112	140	—	3.5	1.1	1.1
—	223	113	200	—	4.0	1.3	0.5
—	230	120	201	—	3.0	0.8	0.7
—	231	121	202	—	3.5	1.1	0.9
—	232	122	203	—	4.0	1.3	1.2
—	300	123	210	—	2.5	1.6	0.7
—	301	130	211	—	4.0	1.1	0.9
—	302	131	212	—	6.5	1.4	1.2
—	310	132	220	—	4.5	1.6	0.9
—	311	140	221	—	7.5	1.4	1.2
—	312	141	222	—	11.5	1.7	1.4
—	313	200	230	—	16.0	0.6	1.2
—	320	201	231	—	9.5	0.9	1.4
—	321	202	240	—	15.0	1.2	1.4
—	322	203	300	—	20.0	1.6	0.8
—	323	210	301	—	30.0	0.9	1.1
—	330	211	302	—	25.0	1.3	1.4
—	331	212	310	—	45.0	1.6	1.1
—	332	213	311	—	110.0	2.0	1.4
—	333	220	312	—	140.0 +	1.3	1.7
—	—	221	313	—	—	1.6	2.0
—	—	222	320	—	—	2.0	1.4
—	—	230	321	—	—	1.7	1.7
—	—	231	322	—	—	2.0	2.0
—	—	240	330	—	—	2.0	1.7
—	—	241	331	—	—	3.0	2.0

TABLE XV—continued.

Number of Tubes of each Dilution.				Number of Tubes of each Dilution.			
2	3	4	5	2	3	4	5
Significant Numbers.				Probable Number of Organisms.			
—	—	300	340	—	—	1.1	2.0
—	—	301	341	—	—	1.6	2.5
—	—	302	350	—	—	2.0	2.5
—	—	303	400	—	—	2.5	1.3
—	—	310	401	—	—	1.6	1.7
—	—	311	402	—	—	2.0	2.0
—	—	312	403	—	—	3.0	2.5
—	—	313	410	—	—	3.5	1.7
—	—	320	411	—	—	2.0	2.0
—	—	321	412	—	—	3.0	2.5
—	—	322	420	—	—	3.5	2.0
—	—	330	421	—	—	3.0	2.5
—	—	331	422	—	—	3.5	3.0
—	—	332	430	—	—	4.0	2.5
—	—	333	431	—	—	5.0	3.0
—	—	340	432	—	—	3.5	4.0
—	—	341	440	—	—	4.5	3.5
—	—	400	441	—	—	2.5	4.0
—	—	401	450	—	—	3.5	4.0
—	—	402	451	—	—	5.0	5.0
—	—	403	500	—	—	7.0	2.5
—	—	410	501	—	—	3.5	3.0
—	—	411	502	—	—	5.5	4.0
—	—	412	503	—	—	8.0	6.0
—	—	413	504	—	—	11.0	7.5
—	—	414	510	—	—	14.0	3.5
—	—	420	511	—	—	6.0	4.5
—	—	421	512	—	—	9.5	6.0
—	—	422	513	—	—	13.0	8.5
—	—	423	520	—	—	17.0	5.0
—	—	424	521	—	—	20.0	7.0
—	—	430	522	—	—	11.5	9.5
—	—	431	523	—	—	16.5	12.0
—	—	432	524	—	—	20.0	15.0
—	—	433	525	—	—	30.0	17.5
—	—	434	530	—	—	35.0	8.0
—	—	440	531	—	—	25.0	11.0
—	—	441	532	—	—	40.0	14.0
—	—	442	533	—	—	70.0	17.5
—	—	443	534	—	—	140.0	20.0
—	—	444	535	—	—	160.0	25.0
—	—	—	540	—	—	—	13.0
—	—	—	541	—	—	—	17.0
—	—	—	542	—	—	—	25.0
—	—	—	543	—	—	—	30.0
—	—	—	544	—	—	—	35.0
—	—	—	545	—	—	—	45.0
—	—	—	550	—	—	—	25.0
—	—	—	551	—	—	—	35.0
—	—	—	552	—	—	—	60.0
—	—	—	553	—	—	—	90.0
—	—	—	554	—	—	—	160.0
—	—	—	555	—	—	—	180.0 +

significant number, the error introduced being considered unimportant.

By referring to the appropriate column in the table (which is reproduced in Table XV) in which the significant number appears, the probable number of bacteria in the volume represented by the first *significant* figure, is obtained, and from this the probable number in x c.c. is easily calculated. Thus, with the example 55410, 541 indicates 17 bacteria in 0.1 x c.c., hence the probable number in x c.c. is 170, or, if $x = 10$, 170 in 10 c.c., *i.e.*, 1,700 in 100 c.c.

A first criticism which can be raised against such a table is that in providing for every possible combination of results it is largely wasted in translating results which should never arise and which, if they did occur in the coliform examination under discussion, would arouse immediate misgivings in the technique. The application of such a table to water examination has its main use only when large numbers of *Bact. coli* are present and when more than an ordinary sanitary interpretation is required. Thus, the comparative impurity of different rivers and the relative value of alternative treatment processes are often best illustrated by this method. Where, however, *Bact. coli* is present in a water in such numbers as to enable a reading to be obtained in this table, the sanitary interpretation usually requires no preliminary calculations or deliberations.

So far, we have considered such probable numbers as being based only on actual *Bact. coli* results. In Report No. 71 (Ministry of Health), however, simpler tables, modified from the above, are included for use with the presumptive coliform reactions. Hence, instead of obtaining the "Probable Number of *Bact. coli*," the "Probable number of probable coliform bacteria" is to be calculated. Much discretion is necessary in interpreting the figure thus obtained, particularly as the presumptive reactions read on the second day of incubation are included. In many instances, especially in surface waters, these second day presumptive reactions carry a high percentage of false or spurious results. The application of these tables to presumptive reactions conveys the undesirable impression of a scientific accuracy which does not exist, and, since the figure given is often quite fictitious, much unnecessary alarm and fruitless effort arise when, as is not infrequent, it is recorded and accepted without due reservation and discretion. The application of confirmatory tests, especially in the case of second day presumptive reactions, may convert significantly high figures obtained on the above basis into zero or negligible counts for *Bact. coli*, or even for coliform bacteria as a whole.

A quick result is often required in water examinations but short cuts in bacteriology involve many fallacies and are therefore to be deprecated unless the limitations are fully realised and due caution observed. To record *Bact. coli* as present in a sample of water without having isolated the organism, or applied any tests but the presumptive reaction, is unjustifiable. It is a serious finding and should not, therefore, be lightly recorded.

Alternative Methods of Examination

The alternative methods suggested in Report 71 and elsewhere have for their main object the identification of *Bact. coli* without the trouble and delay of isolation and differentiation.

A. Primary Incubation at 44° C. The primary tubes are inoculated as before, but are incubated in the 44° C. water-bath with the precautions mentioned on p. 450. The tubes showing gas after twenty-four or forty-eight hours are taken as evidence of *Bact. coli*, whose presence can be expressed as already recommended or the probable number in 100 c.c. can be calculated from the table. The disadvantages of this method are that (a) the presence of all strains of faecal coli is not demonstrated, (b) no information is obtained regarding the other coliform bacteria, and (c) false presumptive reactions may be recorded by this test. Where the facilities are available and speed is essential, this method has, however, some compensatory advantages.

B. Secondary Incubation at 44° C. The primary tubes are incubated at 37° C. for twenty-four to forty-eight hours and positive tubes are subcultured into further tubes which are then incubated in the 44° C. water-bath for twenty-four to forty-eight hours. By this means, in a minimum of two days and a maximum of four days, *Bact. coli* can be enumerated with almost the same accuracy as by the standard plating method. Once again, however, little information is obtained concerning the presence of any of the other coliform bacteria.

In an endeavour to overcome this difficulty, it has been suggested that the 37° C. positive tubes be subcultured into tubes of citrate medium which are observed for growth in the usual way. Positive citrate reactions are only considered when the corresponding 44° C. MacConkey tubes have proved negative, growth in the citrate medium then assuming some importance as indicating the presence of coliform bacteria other than *Bact. coli*. Alternatively the citrate test may not be applied to the 37° C. tube until the corresponding 44° C. tube has given a negative result.

Both of these refinements introduce errors, as many bacteria outside the coliform group are capable of utilising citrate, and the submission of the mixed cultures, which are normally present in water and to a lesser degree in the primary tubes, to the citrate test can provide no reliable information regarding coliform bacteria. The maximum information available refers to bile-tolerant organisms which, in mixed culture, are capable of growing in citrate medium. Moreover, to wait a maximum of four days before performing this "Citrate Test" transforms this "rapid" method into one which is slower than the standard.

A more rational alternative is to plate out the 37° C. tubes which have on subculture given negative 44° C. results, and to differentiate as usual.

Convincing evidence is accumulating as to the value of incubation at 44° C., and Bardsley (1938), Clegg (1942) and others, have reported very favourably in respect of its specificity for *Bact. coli*. For example, Clegg and his co-workers concluded that incubation in MacConkey's broth at 44° C. provided the most reliable single test for the detection of *Bact. coli*. In one series of parallel tests, 97.3 per cent. of coli cultures giving Indole +, Methyl Red +, Voges-Proskauer -, Citrate - reactions yielded positive 44° C. results.

Carried out under strict conditions, incubation at 44° C. appears to provide a reasonably reliable and quick method of ascertaining the presence of faecal coli, but, since it inhibits the growth of other coliform bacteria—and these are not entirely without significance in water examinations—incubation at 37° C. should also be performed.

The 44° C. test can therefore be advantageously carried out (a) for the primary MacConkey cultures, with a duplicate set for incubation at 37° C., and (b) as an additional confirmatory test for faecal coli in isolated cultures.

Significance and Interpretation of Results

Bact. coli

It has already been stated that the examination for *Bact. coli* is the most important single observation in the analysis of water, and that, though their presence in water can never safely be neglected, it is their relative abundance which is of fundamental significance as an index of recent faecal pollution.

The number of viable *Bact. coli* in human faeces amounts to several hundred millions per gramme; if the low figure of a hundred millions be accepted, it follows that the addition of faeces to water, to the extent of only 1 part per hundred millions, would result in the immediate presence of *Bact. coli* in so small a quantity as 1 c.c. The delicacy of the test is therefore considerable. Discussing this point in terms of sewage, Houston (1913 and 1925) remarked that the absence of *Bact. coli* from 1 c.c. of water implies that habitual contamination with sewage or its bacterial equivalent, to the extent of 1 part per 100,000, could be excluded. The absence of *Bact. coli* from 100 c.c. of water would, therefore, eliminate contamination with sewage or its bacterial equivalent in so small a degree as 1 part in 10 million parts of water. As, however, *Bact. coli* gradually dies in water, its presence in small volumes thereof signifies a greater degree of pollution than the above figures indicate, and manifestly the larger the number of *Bact. coli* found, the greater, the nearer and the more dangerous is the pollution.

The greatest importance is attached to the *Bact. coli* findings, but a final judgment regarding a water supply must be made on wider considerations which include a survey of the gathering ground together with physical, chemical and general bacteriological observations on the water. As compared with the other coliform bacteria, *Bact. coli* has a much more limited distribution but is, nevertheless, fairly widespread. Its occasional presence in relatively large samples of even the best waters is, therefore, to be expected, and other things being equal, need give rise to no undue alarm.

Pure waters, such as those purified by nature and yielded by many deep wells and boreholes, and those which have been efficiently purified by artificial means, habitually or in the great majority of samples, contain no *Bact. coli* in 100 c.c. quantities. This finding is, in our opinion, a guarantee, as far as bacteriology is concerned, of the purity and wholesomeness of a water supply, and all efforts should aim at this standard. Certainly, waters entering the distribution system after efficient treatment should show no *Bact. coli* or even coliform bacteria in 100 c.c.

On the other hand, the presence of *Bact. coli*, in all or the majority of representative samples, in comparatively small quantities of water, e.g., 20 c.c. or less, should be taken to indicate fairly recent and poten-

tially dangerous pollution by matter of excremental origin. In the event of Bact. coli being isolated from 1 c.c. or less of a sample, the water should be unhesitatingly condemned as polluted and unsuitable for drinking purposes. It is rarely found that Bact. coli in large numbers is unaccompanied by other evidence, bacterial, chemical and topographical, of pollution.

Waters showing the presence of Bact. coli only in quantities greater than 20 c.c. should be judged with discretion according to other knowledge, geological, topographical, chemical, etc., but, generally speaking, we should advise action in the case of any supply which contained Bact. coli in 50 c.c. or less of water.

In our experience, waters in which Bact. coli can occasionally be found in minimal numbers (1-2 per 100 c.c.), tend in course of time to deteriorate owing to increasing population, industry, surface pollution and demand for water. Warning should, therefore, be given that protective measures may at any time become necessary and that close watch must be kept as more ominous signs may become apparent. Many Chalk-derived supplies, for example, which were at one time regularly free from Bact. coli in 100 c.c., now show the presence of this organism in that and much smaller volumes of water on many occasions of sampling. It is noteworthy also in these cases, as illustrating the delicacy of the Bact. coli examination, that often little or no change is observable in the chemical analysis.

A large and increasing number of water supplies are now being obtained in this country from rivers. These are almost invariably polluted and efficient treatment is essential. We are of opinion, from the examination of many of such supplies, that treatment, whether by filtration and chlorination or by excess lime, can readily and economically yield a product for the most part containing no coliform bacteria in 100 c.c., and we consider that this standard should be attained with river-derived as with other supplies. A study of the recent Reports to the Metropolitan Water Board shows that over 95 per cent. of all samples of final water derived from such polluted sources as the River Thames contain no (typical) Bact. coli in 100 c.c., and our experience of many efficiently treated waters from similar sources is in entire agreement. Before, therefore, a treatment process which includes a bactericidal agent, such as chlorination, can be considered efficient, the final water, whatever its source, should when sampled at the plant be free from Bact. coli (and other true coliform bacteria) in 100 c.c.

Though many natural as well as treated waters do reach this high standard, the occasional presence of Bact. coli or coliform bacteria in small numbers must be expected, especially in samples from the distribution system. In the case of public supplies, however, on at least 90 per cent. of all occasions of representative sampling, the water should be free from Bact. coli in 100 c.c. and the remainder should not contain this organism in less than 50 c.c. Coliform bacteria other than Bact. coli should be absent from 100 c.c. in at least 80 per cent. of samples, and the remainder should not contain such organisms in 10 c.c. of water.

If these standards were applied to small private supplies, such as those to isolated houses and farms, the majority of them would be condemned, many unnecessarily. Most of these supplies are derived from shallow wells, the waters from which are frequently of inferior purity, and in interpreting results considerable reliance must be placed on topographical considerations, *e.g.*, the condition of the well and the proximity or otherwise of sources of pollution. Considering solely the *Bact. coli* examination we are usually satisfied if the results are negative in 20 c.c.

The presence of *Bact. coli* in moorland, upland and lake waters is often excused on the ground of pollution by the excreta of animals and birds, but there are few sources in this country from which human contamination can now be entirely excluded. Moreover, whilst human pollution is of chief importance, animals and birds must be considered as potential agents in the spread of disease to man by the pollution of water supplies. Gulls have already received special mention. The habits of these birds are filthy. They frequent sewage outfalls and may then visit reservoirs and cause serious pollution of the water. Thus, they may infect the water with such disease-producing organisms as typhoid and paratyphoid bacteria. The salmonella or food-poisoning bacteria which affect man may have their origin from animals, such as swine and rodents, and from the excrement thereof gain access to water.

There are other diseases to which both animals and man are susceptible, *e.g.*, undulant fever (due to *Brucella abortus*), and our knowledge of the life history of many pathogenic organisms and viruses is still so limited that transference from animal to man by means of water cannot be excluded. Though our information is as yet largely negative we believe that it is a mistake to ignore, as being unimportant, contamination of water supplies by non-human faecal matter.

We consider, therefore, that it is advisable to apply treatment to water supplies which contain more than minimal numbers of *Bact. coli*, whatever their origin. We see no adequate reason why water supplied for human consumption should ever, so far as its essential and bacterial cleanliness is concerned, depart from the highest standards, since to-day cheap, ready and efficient purification methods are available to achieve this result whatever might be, within reason, the source of the water. No advantage to the public health can possibly result from consuming bacteria of the soil, surface washings, and animal and bird excreta in the water supply, although it might not be capable of proof that such are definitely disease-producing. That impure water bacteria, not associated with specific disease, may give rise to widespread human illness was shown in the outbreak of illness in Poplar, London (Ministry of Health, 1927), when unpurified river water was accidentally supplied to the consumers instead of treated water. A similar experience came to our notice where over a hundred cases of illness, of short duration and characterised by abdominal pain, diarrhoea and vomiting, occurred in a factory where crude canal water gained access to the pure water service.

Widespread outbreaks of gastro-enteritis have been caused by such pollution of water, and water-borne epidemic typhoid fever is sometimes preceded or accompanied by many cases of that illness.

The presence in water of bacteria derived from faeces, sewage and decomposing matter, apart from those known to cause specific diseases such as typhoid fever, etc., may thus give rise to illness of ill-defined character, such as gastro-enteritis. Whilst the pathogenic organisms from the human intestine are most to be feared, this dread should not obscure the outlook, and there appears good reason to believe that certain bacteria, not usually regarded as pathogenic and of animal as well as human origin, are not entirely innocent but may become virulent under certain conditions:

We deprecate, therefore, the attitude so often adopted of ignoring the presence of Bact. coli because it is probably derived from animal excreta. It is not contended that the latter, often present in upland surface waters, are as dangerous and important as human excretal pollution, but the responsibilities of authorities undertaking the supply of water preclude the taking of even the slightest risk. Public water supplies should be beyond suspicion.

It is easy to interpret the Bact. coli results at either extreme, namely, when the organism is absent from 100 c.c. or present in 1 c.c. or less, but with intermediate waters an unqualified opinion regarding their wholesomeness and safety is often difficult to give even with full analytical and topographical knowledge, especially too when an opinion is requested on a single sample. It cannot be too strongly stressed that a verdict given in these cases, though based on a summation of results by the bacteriologist and analyst, assisted by a field survey where possible, is tentative and may not at all times hold good. A definite opinion on a source requires a series of samples taken under varying climatic conditions.

So far, the discussion has been limited to the significance of finding Bact. coli in water. As explained earlier, we prefer, until more accurate information is available, to ascribe much the same faecal significance to Bact. coli, type II, as to type I. The small error (if any) thereby incurred is on the side of safety while the significance of coli II remains obscure. In normal faeces, coli II occurs less commonly than some of the citrate-positive types and might, therefore, and with some justification, be regarded with the same discretion as the other "non-faecal" coliforms, but, whereas these latter do show a marked preponderance in relatively innocent sites, the same cannot be said of coli II which appears to occur more frequently in polluted water than elsewhere. The academic problem largely resolves itself, however, in water examination, for coli II is seldom found in waters which do not also show the presence of coli I.

Coliform Bacteria other than Bact. coli

The significance to be attached to the presence in water of the remaining coliform types has been substantially established, and they are to-day accepted not as indicators of recent excretal pollution but

rather as denoting a later stage when processes of natural purification are in operation. Alternatively, they may indicate atmospheric contamination or the access of surface washings. As shown already, these organisms generally form but a small minority of the coliform bacteria normally present in faeces, but comprise the majority in the case of non-faecal sources such as plants, grains and soil. They are able to survive and apparently to multiply outside the animal body and cannot be considered decadent organisms to the same extent as *Bact. coli* under these conditions. We are in sympathy, however, with the opinion expressed by Bardsley (1934) regarding their distant or remote association with faecal pollution.

Waters which are quite undefiled or efficiently purified do not contain these organisms, nor in fact lactose-fermenters of any kind in the quantities usually examined, and whilst their presence may not be of the dangerous import of *Bact. coli*, they are, nevertheless, in our opinion, a sign of some, even though minor, impurity, and as such should not be dismissed without recognition and investigation. Conditions which allow the access of these organisms to a water supply may at some time permit pollution of a more dangerous character, the potentialities of which should be investigated.

In our experience of dealing with all classes of waters, it is comparatively rare to find these bacteria unaccompanied by *Bact. coli*, though the latter may sometimes be numerically inferior, according to the cultures. Whilst on this point, we would again stress that differential enumerations, as usually conducted, are highly artificial and show not the actual numerical distribution in the water but simply the relative numbers which develop in the laboratory media. It has been shown, for instance, that bile-salt favours the growth of *Bact. coli* at the expense of the other coliforms. This is of advantage in water examination, but does not help research into the absolute proportions in which the various coliform bacteria occur.

The presence of the citrate-positive types in association with *Bact. coli* gives rise to no difficulty, for the presence of the latter is sufficiently significant to warrant the drawing of definite conclusions. It is the presence of those types in the absence of *Bact. coli* which provides a difficult problem in some cases. Their presence demands investigation which may prove their innocence or the necessity for extra protection and close watch on the supply. Surface washings may not always be innocent, and we cannot in this respect do better than repeat the warning given by the late Sir Alexander Houston in his 19th Annual Report to the Metropolitan Water Board, where he stated:—

“Some bacteriologists are a little eager to deny recognition to the aerogenes groups of organisms, because they are apt to be associated with ‘washings’ from grain and soils. Yet it is in times of flood, when all sorts of ‘unchartable’ pollutions are swept into watercourses, that the soil microbes may perhaps be specially noticeable, and few will deny that floods are periods of epidemiological danger.”

We repeat that whilst not of the same gravity as *Bact. coli*, the

presence of the other coliform bacteria is to be regarded as a warning sign, rather than as of no concern. Instances have often arisen in our experience where coliforms, such as *Bact. aerogenes*, found on one occasion, have been later replaced by *Bact. coli* and other definite signs of pollution, occurring, for example, after heavy rainfall.

While the above remarks apply to both treated and untreated waters, it must be clearly understood that no coliform bacteria should be present in 100 c.c. quantities of waters which have received efficient bactericidal treatment, such as chlorination. Though the resistance of the intermediate-aerogenes-cloacæ types is somewhat greater than that of *Bact. coli*, all coliform bacteria are easily destroyed by agents, such as chlorine, ozone, excess-lime, etc., if suitably applied in water purification. The presence, therefore, of any *true* coliform bacteria (as distinct from the presumptive reactions, which may be caused by other organisms) in such a water is *prima facie* evidence that the treatment has been inadequate. Thus, in such cases, the citrate-positive coliforms assume much the same importance as *Bact. coli*. In this respect, however, two modifying factors must be borne in mind : (1) that the citrate-positive types, being so widely distributed, are most apt to gain entrance during faulty sampling, and (2) that, however pure the water may be as it leaves the waterworks, there is always a certain liability to deterioration in service reservoirs and distribution mains. For these reasons, the highest standards should be applied only to treated waters before they enter the distribution system and, in the case of samples taken from consumers' taps, the original distinction between *Bact. coli* and the other coliforms again comes into force. It may be remarked here that anomalous results and much unnecessary alarm could be avoided if those collecting samples were fully conversant with proper methods of sampling and exercised due discretion in the selection of sampling points. The unfortunate proneness to select quite unsuitable scullery or out-door taps and to investigate the bacterial flora contained therein and not in the water gives rise to much unfair criticism of many perfectly satisfactory supplies.

In all considerations regarding the significance of the intermediate-aerogenes-cloacæ types in water, their vitality must be kept in mind, for, as has already been said, some strains can subsist in water for long periods, and we have found multiplication to take place in summer months on filter beds and in reservoirs. The following experience also brings out this point :—

A water supply that we have had under constant observation is derived from the Chalk, which can be regarded as a vast underground storage area. After heavy rainfall, surface water gains ready access by swallow-holes and fissures, when *Bact. coli* is found in abundance, say in 0.1 c.c. of water, while *Bact. aerogenes* is not conspicuous on the platings and may not be isolated from less than 10 c.c. of the water. With the cessation of rain and a period of dry weather the picture alters, *Bact. coli* becoming progressively less and *Bact. aerogenes* more apparent. Finally, a stage is reached where aerogenes types are isolated from, say, 1 or 10 c.c. of water, but *Bact. coli* only from 50 or 100 c.c., if at all.

In general, our experience is that citrate-positive bacteria are not conspicuous in water showing definite evidence of recent pollution by excremental matter. When they are found in the absence of *Bact. coli*, the safest conclusion to draw is (as Report No. 71 concisely states) that they may "herald the advent of more serious pollution." In such cases, however, the subsequent investigations frequently elicit an "innocent" cause, of which perhaps the commonest is faulty sampling, whereby dust or tap slime may gain entrance into the sampling bottle. An unclean bottle used for collection, or contact with the fingers, may likewise account for the findings. The most usual fallacy arises through neglect to sterilise the growth inside the nozzle of the tap, standpipe or pump, wherein the citrate-positives often flourish. While, therefore, the finding of these organisms should be followed by a thorough investigation and a close watch on the supply, in the interests of all concerned, it is only fair to the water undertaking to exclude all innocent possibilities before assuming graver causes.

It was long the experience of workers in the tropics, *e.g.*, India, that the definition and standards of *Bact. coli*, found satisfactory in this country, failed when applied to tropical water supplies. Many of these would, on account of the presence of apparent *Bact. coli*, have been unnecessarily condemned. The prevalence of the aerogenes-cloacæ types in such waters has long been recognised, and the use of the citrate test has revealed the fact that many of the apparent *Bact. coli* were really Intermediates. The supposed discrepancy between standards here and abroad has therefore been considerably reduced, but more tolerance must still be shown to the presence of citrate-positive coliforms than would be justifiable in this country.

Some of the observations of Clemesha in India have already been mentioned. Houston, in this country, did not find any relative increase of *Bact. aerogenes* during the storage of river waters, but Hirst, working in Ceylon, confirmed Clemesha's findings in this respect. These observers found that *Bact. aerogenes* became conspicuous in the lake waters of the Colombo and Madras water supplies respectively, only some days after the occurrence of pollution, whilst *Bact. cloacæ* predominated after long storage and particularly in the deepest layers of the reservoir, from which it appeared that growth was favoured by an acid reaction and a lack of oxygen in the water. The presence of decomposing vegetable matter in water is also favourable to *Bact. cloacæ*.

Presumptive Coliform Test

As already indicated, useful early conclusions may be frequently based on the results of the presumptive coliform test, if read with discretion, and waters at the extreme ends of the scale are sufficiently distinguished for most practical purposes without the need for subsequent differentiation. Thus, considering on the average how large a proportion of presumptive reactions yield *Bact. coli*, the presence of such reactions in small quantities of water, *e.g.*, 1 c.c. or less, quite reasonably precludes the possibility of a supply being adjudged satis-

factory. Where, of course, all the presumptive reactions are negative, the examination is completed. In the great majority of cases, however, it is not desirable to place more than temporary reliance on presumptive findings. When one considers that the expert, armed with the fullest information obtainable from both analytical and topographical data, sometimes has difficulty in assessing the quality of a water, it would appear to us an invidious practice to base final conclusions and set up standards on the ambiguous presumptive results, especially those obtained on the second day of incubation of which a high proportion are false reactions. Justification can rest only on the fact that the wide margin of error is on the side of safety, except when a good supply is wrongly condemned and substituted by an inferior one.

In Report No. 71, standards and classification of waters, based on the presumptive findings, have been suggested as follows:—

		Presumptive Coliform Count per 100 ml.
Class 1 .	Highly satisfactory .	Less than 1
Class 2 .	Satisfactory .	1-2
Class 3 .	Suspicious .	3-10
Class 4 .	Unsatisfactory .	Greater than 10

“ Throughout the year 50 per cent. of samples should fall into Class 1 ; 80 per cent. should not fall below Class 2 ; and the remainder should not fall below Class 3.”

A distinction is made between chlorinated and non-chlorinated waters and it is stated in the Report (a) “ In chlorinated piped supplies the water ought to come into Class 1 ” and (b) “ Efficient chlorination should yield a water free from coliform organisms in 100 ml.”

We agree with the latter statement, but it does not follow that a water which is free from coliform organisms in 100 ml. will fall into Class 1, since this classification is based on the presumptive reaction, which may be false or spurious especially in certain chlorinated supplies. Various spore-forming micro-organisms capable of causing false presumptive reactions occur in surface waters, such as from rivers, and they are resistant to efficient chlorination.

The “ presumptive reaction ” and “ coliform organisms ” should not be used as synonymous terms, and the above classification would have a better foundation and more merit if it were based on some confirmation, even partial, of the presumptive reaction.

In Report No. 71, a distinction is rightly made between samples collected at the waterworks, and samples collected from the distribution services of piped supplies and “ Standards ” based on presumptive reactions have discreetly been omitted in the latter. It is a most valuable Report, which should be periodically revised and re-issued.

AMERICAN PRACTICE

The American Public Health Association and the American Water Works Association in their joint publication "Standard Methods for the Examination of Water and Sewage" (8th edition, 1936), recommend that "the coli-aerogenes group be considered as including all aerobic and facultative anaerobic Gram-negative non-spore-forming bacilli which ferment lactose with gas formation." Primary inoculations of the sample are made into a "standard lactose broth" (which contains no bile-salt) and the production within twenty-four hours of more than "a small bubble of gas" is regarded as a positive presumptive test. The former stipulation that the gas should occupy at least 10 per cent. of the Durham tube no longer appears. The formation of gas between twenty-four and forty-eight hours is not accepted as a positive presumptive test unless (a) subculture into specified inhibitory liquid lactose media results in gas production, or (b) subculture on Endo's agar or eosin-methylene-blue agar gives rise to typical coliform colonies. If subcultures of these colonies on agar slopes show a growth of Gram-negative non-sporing bacilli and in lactose broth give acid and gas within forty-eight hours, the coli-aerogenes test is "completed."

The Completed Test must be applied to all drinking waters which are being assessed for Government standards and the Presumptive Test is reserved for the examination of sewage, sewage effluents and highly-polluted or raw waters. An intermediate form of examination, termed the Confirmed Test, is permissible in certain cases where previous experience has shown it to be in reasonable agreement with the Completed Test.

Differentiation of the various members of the coli-aerogenes group is not at present considered essential in America, but a scheme is outlined whereby the indole, methyl-red, Voges-Proskauer and citrate tests may be applied to the organisms isolated by the Completed Test. The classification suggested is not significantly different from that proposed in Report No. 71. Stress is laid on the fact that differentiation does not detract from the value of the group tests in the routine examination of water supplies.

The discretion exercised with "2nd day" primary fermentations is an evident requirement for the exclusion of false presumptive reactions (*cf.* Table XIII, where, despite the presence of bile-salt, we obtained 26.8 per cent.), but the omission of the 10 per cent. minimum for gas-production in the "1st day" fermentations seems to require some explanation, as in the absence of bile-salt many micro-organisms can produce small quantities of gas from lactose in twenty-four hours. We agree with the emphasis placed on the Completed Test as the *sine qua non* for drinking waters and with the limited reliance placed on the Presumptive Test.

We also commend the efforts made to obtain only true coliform bacteria. Manifestly, no organism should be so considered or its sanitary significance assessed until the correct morphology has been demonstrated

and a pure culture proved capable of fermenting lactose. Since 1936, the value of differentiation may have become more appreciated in America, but the fallacies attendant on unconfirmed presumptive reactions are becoming more and more apparent in this country.

References

- ARKWRIGHT. 1921. *J. Path. & Bact.*, 24, 36.
BARDSLEY. 1934. *J. Hyg., Camb.*, 34, 38.
BARDSLEY. 1938. *J. Hyg., Camb.*, 38, 309.
BERGEY. 1939. "Manual of Determinative Bacteriology."
BUCHANAN and FULMER. 1928. "Physiology and Biochemistry of Bacteria."
CLARK and LUBS. 1915. *J. Inf. Dis.*, 27, 160.
CLEGG and SHERWOOD. 1942. *J. Hyg., Camb.*, 42, 2.
CLEMESHIA. 1912. "The Bacteriology of Surface Waters in the Tropics."
DUDGEON. 1924. *J. Hyg., Camb.*, 22, 348.
EIJKMAN. 1904. *Zbl. Bakt.*, 37, 436, 742.
ESCHERICH. 1885. *Fortschr. Med.*, 3, 515, 547.
FORD. 1903. *Rockefeller Inst. for Med. Res.*, Vol. II.
HARDEN. 1906. *Proc. Roy. Soc., B*, 77, 424.
HEINICK. 1903. *Arch. für Thierheilkunde*, 29, 476.
HIRST. Private Report.
HOUSTON. 1913. "Studies in Water Supply."
HOUSTON. 1925. *19th Annual Rep. to Metropolitan Water Board.*
JORDAN. 1890. *Rep. Mass. Bd. Health*, 11, 836.
KOSER. 1926. *J. Amer. Wat. Wks. Assoc.*, 15, 641.
KRUSE. 1894. *Z. Hyg. Infectkr.*, 17, 1.
LEVINE. 1921. *Amer. J. Publ. Hlth.*, 11, 21.
MACCONKEY and HILL. 1901. *Thomson Yates Lab. Reports*, 4, I., 151.
MACCONKEY. 1905. *J. Hyg., Camb.*, 5, 333.
MACCONKEY. 1909. *J. Hyg., Camb.*, 9, 86.
MCCRADY. 1918. *Canad. Publ. Hlth. J.*, 9, 201.
MACKIE. 1913. *J. Path. & Bact.*, 18, 137.
MALCOLM. 1938. *J. Hyg., Camb.*, 38, 395.
MASSINI. 1907. *Arch. Hyg.*, 61, 250.
MINISTRY OF HEALTH. 1927. *Rep. Publ. Hlth. & Med. Sub.*, No. 41.
MINISTRY OF HEALTH. 1939. *Ibid.*, No. 71.
ROGERS, CLARK and EVANS. 1914. *J. Infect. Dis.*, 15, 99.
RUSSELL and BASSETT. 1899. *Proc. Amer. Publ. Hlth. Assoc.*, 25, 570.
SAVAGE. 1918. *J. Hyg., Camb.*, 16, 3.
SMITH. 1895. *Amer. J. Med. Sci.*, 110, 283.
TOPLEY and WILSON. 1936. "The Principles of Bacteriology and Immunity."
WILSON *et al.* 1935. *M.R.C., Spec. Rep. Ser.*, No. 206.
WINSLOW and FALK. 1923. *J. Bact.*, 8, 237.
WINSLOW and HOTCHKISS. 1922. *Proc. Soc. Exp. Biol., N.Y.*, 19, 314.
WINSLOW, KLIGLER and ROTHBERG. 1919. *J. Bact.*, 4, 429.
WINSLOW and WALKER. 1907. *Science*, 26, 797.
WOOD. 1918. *Inst. Wat. Eng.*, "Studies in the Bacteriology of Water."
WOOD. 1919. *J. Hyg., Camb.*, 18, 46.

CHAPTER XXIX

ORGANISMS RESEMBLING THE COLIFORM GROUP OF BACTERIA

The Glucose-fermenting Non-lactose-fermenting Bacteria

THE bacterial flora of fæces, sewage and soil includes a small proportion of non-sporing bacteria which in some ways resemble the coliform group but are distinguished by inability to ferment lactose. The majority of these non-lactose-fermenters can produce acid and gas from glucose, and some which lack this property are separately described. The glucose-fermenters include various important organisms of disease, such as the Paratyphoid and Salmonella group of bacteria (see Chapter XXXIII), together with a large variety of saprophytes. Of the latter, some are actively proteolytic and are termed *Proteus*; others, more closely related to the coliform group, are designated Paracolon bacteria, of which small numbers are frequently found in fæces.

The Paracolon Bacteria. Inability to ferment lactose (in forty-eight hours) is a constant feature distinguishing this group from *Bact. coli*, and some workers do not regard this distinction as fundamental, but would include the Paracolon bacteria in the coliform group. The resemblance is indeed marked, and both groups are saprophytes which can, in certain situations (*e.g.*, the human urinary tract), develop pathogenic characters. The general view, however, is to exclude non-lactose-fermenters from the coliform group, and we follow this rule in water examination.

Paracolon bacteria can frequently be found in polluted waters, but they have received little consideration, since attention is invariably concentrated on the lactose-fermenters. A number of strains were investigated by Trawinski (1924), who found that all produced indole and had fairly wide fermentative powers. Sucrose, raffinose and the polysaccharides were not attacked, however, and the action on maltose, dulcitol, milk, etc., was variable. Gelatin is not liquefied.

The *Proteus* Group. The *Proteus* bacteria are fairly widely distributed, and are found particularly in decomposing animal and vegetable matter and in sewage. They occur to some extent in fæces, and may be more frequent in the stools of patients who are suffering from intestinal and diarrhoeal diseases. They are not, as a rule, numerous in soil and water.

Under aerobic conditions *Proteus* can digest proteins and liquefy gelatin. It often assists the spore-bearing anaerobes in the putrefaction of organic matter, during which process it produces sulphuretted hydrogen, decomposes urea to ammonia, and reduces nitrates to nitrites and ammonia. Though its activities are almost entirely saprophytic, *Proteus* can, like *Bact. coli* and the Paracolon group, become pathogenic.

The chief characters of *Proteus* may be summarised as follows :—

Morphology. Gram-negative, non-encapsulated, non-sporing rods, usually $1-3\mu$ by 0.5μ in size, but showing considerable variation in length. Motility is generally very active and is seldom absent.

Cultivation. *Proteus* grows readily on ordinary media over a wide temperature range, the optimum being about 37°C . It gives rise to a translucent spreading growth on agar, and rapidly liquefies gelatin. There is, as a rule, no pigment formation. Surface growths of *Proteus* are characterised by "swarming," a process which has been aptly defined as a "progressive surface spreading by the microbes from the parent colony." Wilson and Blair (1927) devised a selective medium containing bismuth, brilliant green and sodium sulphite which inhibits the growth of *Bact. coli* and facilitates the isolation of *Proteus*.

Biochemical Reactions. All strains produce acid and gas from glucose and sucrose; most strains ferment salicin, some maltose, but lactose, dulcitol and mannitol are not attacked. The non-maltose-fermenting strains are slow in their action on sucrose and salicin.

Litmus milk is bleached; clotting, followed by digestion, may occur, or the casein may be digested without the appearance of curdling.

Indole production may or may not occur. It is usually correlated with fermentation of maltose. The Voges-Proskauer reaction is negative and the methyl-red reaction weakly positive or indefinite (pH 5.0-5.5).

The power to decompose urea is regarded as a distinctive character of *Proteus* (see Table I).

TABLE I
SHOWING THE PROMINENT DIFFERENCES BETWEEN THE PRINCIPAL COLIFORM BACTERIA AND THE FÆCAL GLUCOSE-FERMENTERS

	Coliform Bacteria.			Paracolon bacteria.	<i>Proteus</i> .
	<i>Bact. coli</i> .	<i>Bact. aerogenes</i> .	<i>Bact. cloacæ</i> .		
Lactose .	+	+	+	—	—
Gelatin .	—	—	+ slow	—	+ rapid.
Urea . .	—	—	—	—	Decomposed.
Litmus Milk.	A. & C.	A. & C.	A. & C.	Variable	Bleaching and digestion.
Indole . .	Usually +	Usually —	Usually —	+	Variable.
M.R. . .	+	—	—	Usually +	+
Citrate. .	—	+	+	Usually —	Variable.
Sucrose .	±	+	+	—	+

Resistance. *Proteus* is not a resistant organism, and is killed by chlorination almost as readily as *Bact. coli*.

Varieties. There are many members of this group, and they include *Proteus vulgaris* (indole-positive, maltose-positive), *Proteus mirabilis* (indole-negative, maltose-negative) and *Proteus X 19*. The X 19 strain is of particular interest in serology, as it is agglutinated by the blood of patients suffering from typhus fever (Wilson-Weil-Felix reaction).

Certain diseases of salmon and trout are caused by bacteria closely resembling *Proteus*. These organisms (*Bact. salmonicida*) have been isolated from river waters, and they differ from *Proteus* in growing best at temperatures under 20° C. and in producing a dark brown pigment which colours the medium.

The Significance of Glucose-Fermenters in Water. Clemesha (1912) made a study of the glucose-positive, lactose-negative bacteria occurring in human and animal faeces, and found that they seldom exceeded 5 per cent. of the total bile-tolerant organisms. The figure is still lower in temperate climates. It is not surprising, therefore, that faecal glucose-fermenters, when present in water, are usually greatly outnumbered by lactose-fermenters. Moreover, there are a number of glucose-positive, lactose-negative bacteria which are common soil and water organisms and whose presence in water indicates nothing more serious than surface exposure. They include aerobic spore-forming and Gram-positive organisms having no relation to coliform bacteria.

As indicators of faecal pollution of water, the lactose-negative glucose-fermenters are much less certain than the lactose-fermenters, and are not investigated in routine bacteriological examinations. When, however, search is being made for pathogenic glucose-fermenters, such as *Bact. paratyphosum*, it is obviously desirable to be able quickly to recognise and exclude the saprophytes. Houston (1926, 1927, 1928) exhaustively studied the non-sporing, non-lactose-fermenting bacteria present in water, and demonstrated that comparatively few tests—morphological, fermentation and indole-production—sufficed to distinguish these from the pathogens. Serological reactions are now employed as the final tests. It can, however, be safely accepted as a general rule that pathogenic bacteria, which might gain access to water and disseminate disease, such as typhoid or paratyphoid fever, would be accompanied by such an enormously greater number of lactose-fermenters as would readily condemn the water.

Until recently, glucose bile-salt peptone water (the original MacConkey Broth) was used as the primary culture medium for the coliform examination, and, from tubes showing acid and gas, subcultures were made into lactose broth for the presumptive coliform reaction. This procedure was our standard practice for many years and has certain advantages in routine work:—

- (1) Attenuated forms of *Bact. coli* seem better able to develop in a glucose than in a lactose medium, and the delicacy of the coliform examination is somewhat greater than when lactose is used as the primary medium.

- (2) The presence of the glucose-positive, lactose-negative bacteria is

demonstrated, and though their importance is small as compared with the lactose-fermenters, the advent of glucose-fermentation in a water supply hitherto free therefrom may give warning of pollution long before lactose-fermenters make their appearance.

Time is saved, however, by using lactose in the primary medium and the results are sufficiently accurate for practical purposes, but there are certain special cases where primary glucose medium is of particular value. For instance, in investigations of purification processes, glucose medium allows better comparisons as it shows changes with a wider range of organisms. It might have advantages when search is being made for pathogenic organisms. The isolation of pathogens from water demands, however, special methods and the use of special culture media, and these are described in Chapter XXXIII.

Non-glucose-fermenting bacteria

Saprophytic bacteria which, in the presence of bile-salt, can ferment neither lactose nor glucose comprise the great majority of the normal water organisms and only a very small proportion of the normal faecal flora. Enumeration of such bacteria is, therefore, all that is usually required in the examination of water, as even the purest water can be expected to contain a few bacteria, and it is only the presence of large numbers which may be significant. Many types of bacteria come within this category and they have already been discussed in Chapter XXVI and their enumeration described in Chapter XXVII. A small number are bile-tolerant, Gram-negative, non-sporing rods of which two named species are *Bact. alcaligenes* and *Bact. pyocyaneum* (*Ps. pyocyanea*). These occur infrequently in faeces and may, in certain circumstances, demand special attention in water examination.

Bact. alcaligenes. The group of bacteria represented by this organism seldom occur in normal human faeces, and then only in small numbers, but they may become more abundant in the stools of patients with intestinal inflammations or other diarrhoeal conditions. They are generally regarded as saprophytes, though one variety has been considered to be the causative organism of a paratyphoid-like fever in the Near East. *Bact. alcaligenes* is not often found in water, but may be occasionally isolated therefrom during an investigation for pathogenic bacteria. Its chief characters are as follows:—

Morphology. A motile, non-sporing rod, about the common size of *Bact. coli*, non-encapsulated, non-acid-fast and Gram-negative.

Cultivation. It grows readily at 37° C. in ordinary laboratory media giving appearances very similar to those of the typhoid-paratyphoid group. Gelatin is not liquefied.

Biochemical Reactions. It differs from all the bacteria already considered in being unable to ferment any carbohydrate, neither acid nor gas being produced. Indole is not formed from peptone water. Litmus milk rapidly turns blue, owing to the production of alkalinity without any preliminary acidity. No clot is formed.

Its negative fermentative characters and the immediate production

of alkali in litmus milk differentiate it from the typhoid-paratyphoid group without the aid of serological reactions.

Resistance. Bact. alcaligenes is not possessed of any unusual powers of resistance and is readily destroyed by chlorination.

Distribution. Though it occasionally occurs in faeces it seems to have a much wider natural distribution, and, when it has been found in water and distinguished from Bact. typhosum, it can be dismissed as of no definite significance.

Bact. pyocyaneum (Ps. pyocyanea). Bact. pyocyaneum, the cause of greenish-blue discoloration of pus, was described by Gessard in 1882. It is sometimes present in the stools of patients suffering from diarrhoea or enteritis, and may rarely be obtained from the excreta of man and animals showing no signs of ill-health. Sewage and water may therefore contain this organism.

Bact. pyocyaneum resembles Proteus in liquefying gelatin, but it is characterised by the formation of greenish-blue and yellow pigments.

It is closely related to a group of fairly common water bacteria, represented by Bact. fluorescens, of which there are gelatin-liquefying and non-liquefying varieties.

Morphology. Bact. pyocyaneum is an actively motile, non-encapsulated, non-sporing, Gram-negative, rod-shaped organism about 2μ to 3μ by 0.5μ in size, but subject to variation.

Cultivation. Growths of this organism are characterised by their greenish-blue coloration. Bact. pyocyaneum grows readily aerobically on ordinary media at blood heat, but coloration is favoured by a lower temperature, 25°C . Oxygen is required to obtain the greenish-blue colour, which diffuses throughout the medium.

On agar there is a profuse spreading moist growth with fluorescent yellow-greenish-blue coloration. Gelatin is rapidly liquefied and the liquid is coloured. Serum is also liquefied. Neutral-red bile-salt lactose agar shows a dirty or smoky yellowish-green fluorescent growth.

Growth readily occurs in nutrient and MacConkey broths, peptone water and other liquid media; the coloration develops at the surface, and shaking of the culture tubes (aeration) often brings out the colour when not apparent.

Biochemical Reactions. Bact. pyocyaneum resembles Bact. alcaligenes in its lack of fermentative ability. Gas is not formed in any of the carbohydrate media, and acid seldom develops, though some strains produce acidity in glucose medium. Litmus milk is decolorised, peptonised, and turned greenish-blue.

Indole is seldom produced.

Pigment Formation. Bact. pyocyaneum produces in its growth a yellowish-green fluorescent pigment—fluorescin—and a blue non-fluorescent pigment—pyocyanin. The former is non-specific, being also produced by water and soil organisms, such as Bact. fluorescens liquefaciens, while pyocyanin is specific to Bact. pyocyaneum.

Fluorescin. Fluorescin is soluble in water, insoluble in chloroform, decolorised by acids and the colour restored by alkalis.

Pyocyanin. Pyocyanin is soluble in chloroform and crystallises as fine long blue needles, which are soluble in water, turned red by the addition of acid and then are insoluble in chloroform.

A third pigment, which is bright red and called pyorubrin, has been described, but whether this is a distinct substance or a derivative of pyocyanin is uncertain. Old cultures tend to lose their ability to produce pyocyanin.

Pigment is best formed in young cultures at room temperature, and oxygen is essential. Bile-salt is not inhibitory and growth with pigmentation may occasionally be seen in water cultures in bile-salt lactose broth.

Growths of *Bact. pyocyaneum* are doubtless unobserved in primary inoculations of water in MacConkey broth owing to :—

1. The fact that mixed cultures are detrimental to pigment formation.
2. The temperature of incubation is above the optimum for pigment formation.
3. Insufficient time of incubation.

A proteolytic ferment, pyocyanase, can be extracted by chloroform from killed cultures.

Resistance. *Bact. pyocyaneum* is readily killed by heat and disinfectants, and is destroyed by the small doses of chlorine used in water-works practice.

The fluorescent bacteria, however, are said to be more resistant to sunlight and ultra-violet light (Burge and Neill, 1915).

Varieties. *Bact. pyocyaneum* typically produces both pyocyanin and fluorescin, but either of these pigments may be absent. The relationship between *Bact. pyocyaneum* and the green-fluorescent pigment-producing bacteria (*Bact. fluorescens*) often found in water is uncertain. The latter are of two types, occurring with about equal frequency, one liquefying gelatin (*Bact. fluorescens liquefaciens*), the other failing to do so (*Bact. fluorescens non-liquefaciens*).

Culturally the former is closely similar to *Bact. pyocyaneum*, except that pyocyanin is not formed, but since *Bact. pyocyaneum* may lose this property, it may be necessary to resort to biological tests for pathogenicity to reach a decision. *Bact. fluorescens* is morphologically similar, ferments no carbohydrates apart from acid formation in glucose, and does not produce indole.

The optimum temperature for growth (not pigment formation) of *Bact. pyocyaneum* is higher (37° C.) than that of *Bact. fluorescens* (25° C.).

Blue milk may be caused by bacteria of this group, such as *Bact. cyanogenes*.

Soil contains bacteria capable of forming green colour and fluorescence in cultures, *e.g.*, *Bact. denitrificans fluorescens*. This organism takes part in the nitrogen cycle, producing nitrogen from nitrates. Its growth in gelatin is accompanied by bright green coloration, but no liquefaction.

The experiments made by Houston, of adding *Bact. pyocyaneum* to sewage, recorded in the Fourth Report of the Royal Commission on Sewage Disposal, indicated that this organism did not long survive, and it is probable that the non-pyocyanin-producing types found in water, such as *Bact. fluorescens*, are to be regarded as distinct organisms rather than altered forms of *Bact. pyocyaneum*.

Bact. pyocyaneum does not occur in pure waters and, when found, it is accompanied by other faecal organisms, such as *Bact. coli*. Its presence should, in our opinion, be regarded as an additional indication of pollution.

We have found it on a number of occasions, and its possible association with a serious outbreak of diarrhoea has been recorded (Thresh, 1903). In this epidemic there were about 1,000 cases of diarrhoea with fourteen deaths. An exceptionally heavy rainfall had washed manurial matter into a service reservoir, and *Bact. pyocyaneum* was found in the water.

An outbreak of diarrhoea was reported by the New York Board of Health in 1898 to be attributable to the presence of *Bact. pyocyaneum*.

In another case, a water supply obtained from boreholes in the Chalk several cottages were attacked by diarrhoea, and in the absence of any apparent cause, the water supply, derived from a shallow well, was examined. The water was undoubtedly polluted, but a possibly significant finding was the isolation of *Bact. pyocyaneum* from the cultures.

In another case, a water supply obtained from boreholes in the Chalk was under suspicion of disseminating paratyphoid fever, and the bacteriological examinations revealed the presence of *Bact. pyocyaneum* as well as *Bact. coli*.

Whether *Bact. pyocyaneum* was cause or effect in these cases is difficult to say, but it is comparatively rare to isolate this organism from water, and most of our instances have been samples from supplies especially examined because of the occurrence of illness with diarrhoea among the consumers.

References

- BURGE and NEILL. 1915. *Amer. J. Physiol.*, 38, 399.
CLEMESH. 1912. "The Bacteriology of Surface Waters in the Tropics."
HOUSTON. 1926. *21st Ann. Rep. to the M.W.B.*
HOUSTON. 1927. *Ibid.*, 22nd.
HOUSTON. 1928. *Ibid.*, 23rd.
THRESH. 1903. *Brit. Med. J.*, Sept. 26th.
TRAWINSKI. 1924. *Zbl. Bakt.*, I, Orig., 92, 356.
WILSON and BLAIR. 1927. *J. Hyg., Camb.*, 26, 374.

CHAPTER XXX

INTESTINAL ORGANISMS USED AS INDICES OF POLLUTION

Fæcal Streptococci

STREPTOCOCCI are spheroidal or ovoid organisms (generally about 1μ in diameter) which multiply by dividing regularly in one plane. The daughter cells tend to adhere together, forming chains of variable length. There are many cocci which divide in this manner and the group includes members showing great differences in biological properties. Some species are highly pathogenic and are responsible for much severe and fatal human illness, whilst others are lacking in virulence and appear to be purely saprophytic. The streptococci, as a whole, are associated chiefly with the human and animal body, being the causal organisms of many inflammatory conditions, but they also occur as saprophytes on the skin, in the mouth and throughout the alimentary canal.

The need for distinguishing between these varieties led to numerous attempts at classification. Early investigators tried, without success to correlate pathogenicity with the length of the chains. Fermentation reactions, also, proved too variable to be of reliable assistance. Cultivation of the organisms in the presence of blood was more helpful as the majority of the pathogenic strains caused hæmolysis of the red blood corpuscles, and, for some time, hæmolytic and non-hæmolytic varieties came to be regarded as virulent and avirulent respectively. The introduction of serological tests, however, showed that this view was not entirely correct and has gone far to define the position of the pathogenic streptococci, of which many types are now recognised, but much still remains to be done with regard to the avirulent varieties.

For the water bacteriologist, however, these difficulties are largely resolved, since he need be concerned only with one variety—*Streptococcus fæcalis*—and this type has certain well-defined characters which clearly distinguish it from the other streptococci. Its natural habitat, like that of *Bact. coli*, is the intestine and its resistance, unlike that of most of the other streptococci, is such that it can survive for some time in water.

Characters

Morphology. Ovoid cells, rather larger than most streptococci, occurring usually in pairs or short chains. They have no capsule and are non-sporing, non-motile and Gram-positive.

Cultivation. They are aerobic and facultatively anaerobic and

differ from many streptococci in growing well on the ordinary laboratory media at 37° C. and 20° C. On solid media they produce, for streptococci, relatively large colonies of 1 mm., and, in broth, growth is profuse with a uniform turbidity. They are tolerant of a wide range of reaction and can grow in the presence of bile-salt. Unlike other streptococci, they can thus develop on MacConkey agar, and produce deep-red "pin-point" colonies. No hæmolysis occurs in blood media and usually gelatin is not liquefied.

Fermentation Reactions. Acid is produced in glucose, lactose, mannite, salicin and usually in sucrose, but not, as a rule, in raffinose or inulin. No gas is produced from any carbohydrate. Litmus milk is acidified, bleached and clotted.

Resistance. *Streptococcus fæcalis* (or *Enterococcus* as it is sometimes called) is characteristically resistant to heat, surviving a temperature of 60° C. for thirty minutes. It survives drying for long periods and can remain alive on culture media, such as gelatin, for years. Chlorination in doses sufficient to kill *Bact. coli* may not completely destroy the fæcal streptococci.

Pathogenicity. Usually nil.

Distribution

As its name implies, *Streptococcus fæcalis* principally occurs in the fæces. Human fæces may contain these cocci to a variable extent up to 100,000 or more per gramme, depending on race, climate, diet and health. They are similarly present in the excreta of animals and may numerically rival the coliform bacteria, though usually much inferior. Small numbers of the other types of streptococci may occasionally be found in fæces, such as mouth streptococci, swallowed in the saliva and food and passing through the intestines as passengers.

Sewage contains fæcal streptococci in appreciable number but not generally exceeding about one-tenth the number of coliform bacteria. Soil, water, etc., subject to manurial or sewage pollution, are thus found to contain these cocci, but otherwise, as in virgin soil and unpolluted waters, streptococci are absent.

Heat-resisting streptococci were so constantly found in milk that they were termed *Streptococcus lacticus*, though the organisms appear to be identical with *Strept. fæcalis* and there is strong presumptive evidence that they are fæcally-derived. (Milk, however, may also contain virulent streptococci, arising from mastitis in the cow or from infection by the milker or those handling the milk.)

Excretally polluted waters may thus contain fæcal streptococci, though not usually in such large numbers as *Bact. coli*. The other varieties of streptococci may also gain access to water, particularly in the case of bathing pools, being derived from the skin and mucous membranes of the bathers. In such cases, however, the transmission of disease is more likely to occur directly from one person to another than by the intermediary of water.

Methods for the Detection of Streptococci in Water

The search for streptococci in water, if it is made at all, is merely undertaken as an extension of the coliform examination, *i.e.*, to confirm or supplement the *Bact. coli* findings. The pathogenic streptococci, as in the case of other disease-producing bacteria, are not primarily investigated, the presence of faecal streptococci being sought merely as a subsidiary index of faecal pollution.

The detection and isolation of the faecal streptococci can be conveniently effected by utilising the presumptive tubes used for the coliform examination. All, or a representative proportion, of the tubes showing acid, or acid and gas, are well shaken, and 1 c.c. portions removed and added to 9 c.c. of sterile water contained in small test tubes. These dilutions are immersed in the water-bath at 60° C. for fifteen to twenty minutes, and subcultures then made on MacConkey agar in the same manner as in the *Bact. coli* examination. The inoculated plates are then incubated at 37° C. for twenty-four to forty-eight hours when faecal streptococci appear as pin-point red colonies. These are picked off and examined microscopically. This usually suffices to complete the examination, but, if required, subcultures can be made and the further characters of faecal streptococci established.

A quantitative result can be expressed in the same way as in the case of *Bact. coli*.

The Significance of Streptococci in Water

Streptococci are used as an indicator of pollution on the same grounds as *Bact. coli*, namely :—

1. They are present in faeces and sewage and are found in known polluted waters.
2. They are not found in pure waters, virgin soil and sites out of contact with human and animal life.
3. They do not multiply outside the animal body (except in such media as milk).

As regards their numbers in faeces and sewage, streptococci are subject to great variation, and whilst at times they may be almost as numerous as *Bact. coli*, at other times they may be considerably less numerous and comparatively absent. As a class, streptococci rapidly die out in water, and are frequently not to be found in waters known to be recently fouled, and showing distinct analytical and bacteriological evidence of the pollution.

Houston (1910) found that in 312 samples of raw river water (Thames, Lee and New River) streptococci were isolated from 1 c.c. quantities only on fifty-one occasions (16 per cent.). It can be said with certainty that coliform bacteria would be isolated from that quantity of water in at least 80 per cent. of samples.

Clemesha (1912), working in India, isolated streptococci from 20 c.c. quantities of water only on six occasions out of 378 samples, 151 of which were grossly polluted. He concluded that streptococci were

infinitely rarer in rivers and lakes in India than in England. Savage and Read (1916) record the following relation of streptococci to coliform bacteria : Of 1,814 samples of water (974 surface supplies and 340 deep well supplies), 510 contained coliform bacteria in 1 c.c. or less, 256 contained streptococci in 1 c.c. or less, 169 contained streptococci in 10 c.c. but not in 1 c.c., and 85 did not contain streptococci in 10 c.c.

Our own experience is that in English waters of all kinds, rivers, wells, etc., at least 50 per cent. of the samples that are polluted and show *Bact. coli* in small quantities of water, as 1 c.c. or less, do not contain streptococci in an equivalent amount of water, and frequently not in ten times that amount. The following is an example of a water (spring) subject to pollution, samples of which we examined at weekly intervals :—

TABLE I

No. of Samples.	Average Agar Count. 37° C 1 c.c.	Average Gelatin Count. 20° C 1 c.c.	Number of Samples containing					
			Bact. coli in			Streptococci in		
			100 c.c. or less.	10 c.c. or less.	1 c.c. or less.	100 c.c. or less.	10 c.c. or less.	1 c.c. or less.
56	57	420	56	52	23	29	4	1

Streptococci do not provide so delicate an indicator of contamination as *Bact. coli*, and failure to find them in water is not a safe guide in framing an opinion as to the sanitary quality of the supply. The test for streptococci should never be employed in the place of and as a substitute for the *Bact. coli* examination.

Houston, who first investigated the question of streptococci, found that as a class they rapidly die out in water, and experiments by Savage and Wood (1918) indicated that when human fæces, animal excreta or domestic sewage are added to water, streptococci tend to diminish and die out rather more quickly than *Bact. coli*. In the tropics it would appear from the work of Clemesha that streptococci die out in water with very great rapidity, so that they are only found practically at the site of the addition of sewage to a river.

On the other hand, Horrocks (1901) found streptococci to persist in sewage after the disappearance of *Bact. coli*, and had similar experience with polluted waters.

The presence of streptococci in water in association with *Bact. coli* is to be regarded as further confirmation of excremental pollution, but a negative result does not lessen the significance of the *Bact. coli* findings. In our opinion the streptococcus test is entirely subordinate to the *Bact. coli* examination, and as a rule adds little of value to the routine bacteriological examination of water for sanitary purposes.

If for research, or other reasons, examination for faecal streptococci is required, the use of tellurite lactose broth and tellurite lactose agar (see Report No. 71, Ministry of Health) will be found helpful in their isolation from water.

References

- CLEMESHA. 1912. "The Bacteriology of Surface Waters in the Tropics."
HORROCKS. 1901. "Bacteriological Examination of Water."
HOUSTON. 1910. 5th Research Report to Metropolitan Water Bd., London.
SAVAGE and READ. 1916. *J. of Hyg.*, 15, 334.
SAVAGE and WOOD. 1918. *J. of Hyg.*, 16, 227.

CHAPTER XXXI

INTESTINAL ORGANISMS USED AS INDICES OF POLLUTION

THE SPORE-FORMING ANAEROBES (CLOSTRIDIA)

THIS group of organisms has been extensively studied since 1914, owing to the part they played in augmenting the war casualties by causing gas gangrene in wounds. The development of better methods for anaerobic cultivation demonstrated that some of the earlier descriptions of the members of this group were inaccurate, owing to the impurity of the cultures then studied. Thus, it was clearly shown that the *B. enteritidis sporogenes* of Klein was a mixture of at least two organisms, *i.e.*, *B. aerogenes capsulatus* of Welch and Nuttall and *B. sporogenes* of Metchnikoff. All the members of this group have now been given the generic title of *Clostridium*, hence the two just mentioned are now referred to as *Cl. welchii* and *Cl. sporogenes*, whilst the term "*B. enteritidis sporogenes*" has disappeared from bacteriological literature. The reaction in milk, described by Klein as given by his bacillus, is typically produced by *Cl. welchii*.

The Reports issued by the Medical Research Council in 1919, together with their War Memorandum of 1940, have cleared much of the early confusion and provided accurate descriptions of a large number of *Clostridia*. For the purposes of this book, however, only a brief review is required.

Distribution

The *Clostridia* and their spores are widely distributed in nature, but they are for the most part essentially associated with the intestines of man and animals, though a few strains may have their natural habitat in soil and decaying animal and vegetable matter. It is the intestinal association which is of significance to the water bacteriologist, but the spores, by virtue of their great powers of resistance, can withstand adverse conditions and survive for long periods in excreta, manure, earth, water, etc.

They are constantly present in human and animal faeces, though generally in much smaller numbers than *Bact. coli*, being seldom recovered from less than 1/100,000th of a gramme. It is also found that, based on the stormy fermentation test in milk, their presence can invariably be demonstrated in sewage in from 1/100th to 1/10,000th of a cubic centimetre. The researches of Houston show that the spores are often absent or only sparsely present in the excreta of birds.

Soil and mud, wherever exposed to sewage or manurial contamination, even considerably remote, show the presence of these spore-

They are not killed by drying and hence often appear in dust. Though their presence has been recorded in virgin soil, they are infrequent and in small number, and it is generally true that the greater the degree of manurial pollution, the larger the number of anaerobes and their spores.

Also, they are comparatively absent from cleanly produced milk, or shellfish obtained from unpolluted layings, but are numerous in both cases when faecal contamination occurs. Waters obtained from unpolluted sources, such as boreholes, are free from these spores in 100 c.c. or more, but those subject to sewage pollution, *e.g.*, many rivers and shallow wells, invariably give positive reactions in quantities of 0.1 c.c. to 100 c.c.

As already mentioned, the Clostridia assumed great importance during the last war, and they were isolated from wounds complicated by gas gangrene which was particularly prone to occur in those areas where the land was cultivated and heavily manured. In civil life, they occasionally complicate infections in man, and they are of considerable importance in veterinary practice, causing such diseases as blackleg and braxy.

In general it can be said that the anaerobes are widely distributed and that there is close correlation between their frequency and the degree of faecal pollution; also that they are numerically inferior to *Bact. coli* except in old and discontinued pollution, where the ratio is altered by the death of *Bact. coli* and the survival of the more resistant Clostridia. The commonest type of these anaerobes is that represented by *Cl. welchii*.

Classification

The group is composed of many members, some of which have been defined and named, whilst others have so far been insufficiently studied

TABLE I. SPORE-BEARING ANAEROBIC BACTERIA
(Abridged from the M.R.C. War Memorandum, No. 2, 1940)

Organism	Surface colonies	Deep colonies in agar	Litmus milk	Coagulated serum or egg.	Spores
<i>Cl. welchii</i>	Large, regular, probably haemolytic.	Lenticular, opaque.	Stormy acid clot. ¹	—	Seldom seen in culture.
<i>Cl. septicum</i>	Transparent, spreading.	Transparent, branching.	Little change.	—	Central or subterminal.
<i>Cl. sporogenes</i>	Medusa head (if plate dry); irregular (if plate moist).	Woolly, opaque.	Digestion with foul odour.	Digestion	Central or subterminal.
<i>Cl. tetani</i>	Very transparent, spreading.	Delicate filaments.	Little change.	—	Terminal, round.

¹ This appearance may be simulated by certain other microbes.

to be considered separate species, and remain unnamed. The Committee of the Medical Research Council based their 1919 classification of the anaerobes on morphology (*e.g.*, shape and position of the spores) together with the relative preponderance of saccharolytic or proteolytic properties. More emphasis, however, is now placed on colony characters, and the findings of the 1940 War Wounds Committee are summarised in Table I.

Characters

Morphology. The rods vary considerably in size, shape and arrangement. Spores are formed, more readily in some types than in others, and the position and shape of the spore is variable (see Table I). The spores are wider than the rods, hence there is distension of the latter. Capsules are present in some members (*Cl. welchii*). Motility is variable and may be absent (*Cl. welchii*), but is more often present and sluggish. The Clostridia are Gram-positive, but old cultures tend to become Gram-negative. Granularity may appear in some types when stained (*Cl. welchii*).

Cultural Characters. The degree of anaerobiosis required is variable; some types are strict anaerobes, whilst others, *e.g.*, *Cl. welchii*, are not. Cultivation and isolation in pure culture are extremely difficult, and apparatus for anaerobic incubation of cultures, such as the McIntosh and Fildes jar, is necessary. Such isolation is not required in routine water analysis.

The optimum temperature is mostly 37° C. Growth is generally slow, but is improved by the addition of blood or serum to the medium. The appearances of the colonies on agar show great variation, even with a pure culture. The media most used in the study of this group (see M.R.C. Reports) are:—

Agar, glucose agar, and blood agar.
Glucose sulphite iron agar (Wilson and Blair, 1924).
Gelatin.
Coagulated serum and egg.
Milk.

In water practice, milk is generally used, but the medium of Wilson and Blair is also recommended.

Fermentation Reactions. The anaerobes can ferment glucose and maltose with the production of acid and gas. Mannite is seldom affected, but some types ferment lactose and sucrose. Large volumes of gas are often formed, and the torn and ragged nature of the clot produced by growth in milk (stormy fermentation) is due to this fact. Volatile and foul-smelling acids, such as butyric acid, may be produced. It is to be noted that the ability of, for example, *Cl. welchii* to ferment lactose may interfere with the presumptive coliform test, for *Cl. welchii* is not a strict anaerobe and can grow in MacConkey broth.

Resistance. This property is of considerable importance. The Clostridia by the formation of spores are able to resist adverse factors

and to maintain their viability and potential activity for long periods. The resistance to heat is considerable, and the spores of *Cl. welchii* in water may not be destroyed by boiling for fifteen minutes. The spores of *Cl. sporogenes* have been found to survive exposure for eight days to a 5 per cent. solution of phenol. Chlorine, in the doses used in water sterilisation, does not destroy spores; in fact, it is often found that, with a given water, stormy fermentation in milk results more quickly from a chlorinated sample than from an equal volume of the unchlorinated water. Similar resistance is shown to other chemical disinfectants. The spores survive drying, sunlight, ultra-violet light, ozone and excess lime. Apart from sedimentation and filtration methods, there is no ready means of removing the spores from water.

Pathogenicity. The disastrous effects of the presence of these organisms in wounds have already been mentioned. Many of them destroy human life by the production of toxins, and toxæmia is an important factor in gas gangrene. For such effects to be produced, the Clostridia must become fairly deeply embedded in the tissues (*e.g.*, via a wound). There is no evidence, however, to show that their presence in the intestinal tract is injurious. The fact that they are constantly found in the fæces of healthy persons would seem to disprove this possibility. Nevertheless, various human illnesses have in the past been ascribed to absorption of toxin due to the undue prevalence of *Cl. welchii* in the alimentary canal, but no substantial evidence has been forthcoming to confirm such theories.

The presence of *Cl. welchii* in a water supply was suspected by Lerner (1922) of causing gastro-intestinal disturbances, but proof was again lacking. On the other hand, there are many communities in England consuming, without apparent ill effects, water which always contains *Cl. welchii*. Moreover, it is more than probable that a far greater number of spores are ingested in milk, ice-cream, butter, shellfish and other foods, than in water. Polluted water supplies, which at one time gave rise to outbreaks, have, since the advent of chlorination, been used with complete freedom from such illness, and chlorination does not kill the sporing bacteria. Up to the present, we consider there is no reason to regard the mere presence of *Cl. welchii* and similar organisms in water as harmful, though we agree that their absence is preferable.

Characters of *Cl. welchii*

A detailed description of the various other members of the group is beyond the scope of this book, and for waterworks practice only *Cl. welchii* need be considered. It was first described as *B. aerogenes capsulatus* by Welch and Nuttall in 1892. Its name was later shortened to *B. welchii*, by which title it has been known until the recent introduction of the term *Clostridium*.

Morphology. Large, non-motile, capsulated rods, averaging 4-8 μ in length and nearly 1 μ in breadth; pleomorphism is marked. Young

cultures are Gram-positive and may show a granular appearance, the staining is variable and older cultures tend to become Gram-negative.

The spores are oval and subterminal in position, but are usually seen free from the vegetative forms. Spore formation does not appear to take place in media containing sugar.

Cultivation. The optimum temperature is 37° C. Strict anaerobiosis is not essential. *Cl. welchii* will develop in the bottom of tubes of liquid media, such as MacConkey broth, or in de-aerated milk covered with a thick layer of prepared paraffin wax. In such milk there is rapid formation of acid and clot, together with much gas which produces a ragged or spongy appearance of the clot—*stormy fermentation*. In meat medium, a pink colour, besides acid and gas, is produced on anaerobic incubation. No digestion occurs, and the odour is sour but not putrefactive. Rapid growth takes place in glucose broth, with formation of acid and gas. On agar, round colonies appear, being at first translucent, but later becoming granular, opaque, yellow-brown and crenated. Gelatin is liquefied.

Fermentation Reactions. Acid and gas are produced in glucose, lactose and saccharose, but not in dulcitol or mannitol. Several strains of *Cl. welchii* are distinguished according to their fermentative action on inulin and glycerol. Indole is not produced.

Resistance. Spores resist heating at 80° C. for one hour, and boiling for several minutes, depending on the nature of the medium. In cultures, the bacteria soon die out, owing to the acidity produced (pH 4.5), but spores can survive for years in sugar-free media, coagulated serum, etc.

Examination of Water for Spores of *Cl. welchii* and allied Anaerobes

The examination of water for evidence of the presence of Clostridia usually consists of a test whereby the existence of their spores is demonstrated. No effort is made to decide to which particular member or members of the group the spores belong, it being assumed that all are, for the purposes of water examination, of the same and equal significance.

The commonest test employed is that whereby characteristic changes, the so-called "stormy fermentation," are produced in milk by the germination therein of spores and subsequent bacterial multiplication. This reaction is typically given by *Cl. welchii*.

The Clostridia rarely occur in any appreciable number in potable water, hence comparatively large samples are required for their detection. River and other polluted waters contain them in greater number, and, in such cases, smaller quantities suffice for the examination.

It is manifestly inconvenient to incubate such large volumes of water as $\frac{1}{2}$ or 1 litre, and though concentration methods can be applied, the reward is rarely commensurate with the labour expended. With

the majority of samples of water, quantities of 100 c.c. and 10 c.c. only are tested, and of known impure waters smaller amounts, *e.g.*, 10 c.c., 1 c.c., 0.1 c.c., etc., are taken.

The skimmed milk is distributed into long-necked flasks (of 150 c.c. capacity for 100 c.c. quanta of water) and tubes (for the smaller volumes of water). The quantities of milk added to flasks and tubes are respectively 50 c.c. and 10 c.c. Each container also receives 5 c.c. of a mixture (M.P. approx. 45° C.) of equal parts of paraffin wax and vaseline and is thereafter plugged and sterilised.

The inoculated flasks and tubes are heated in water to 80° C. and kept at that temperature for fifteen minutes. The air is thus expelled and vegetative organisms destroyed, whilst spores, if present, remain viable. During the heating process the wax melts and rises to the surface, forming a plug which solidifies on cooling and provides an obstruction to the return of air to the medium. Strict anaerobiosis is not obtained by this method, but conditions sufficiently favourable for *Cl. welchii* are provided. Alternatively, the cultures can be placed in an apparatus for maintaining anaerobiosis, such as that of Bulloch, or McIntosh and Fildes, but we have found the wax method simple and adequate.

Incubation takes place at 37° C. for four days, with inspection daily. The greater the number of spores originally present, the earlier is stormy fermentation produced. Thus, with polluted waters, the reaction may be apparent after twenty-four hours. More often, however, two to four days are required. Acidity, clot and much gas are produced. The coagulated casein rises to the surface, has a pinkish or light brown colour, and is ragged, spongy and torn by gas which also blows the seal of wax to the top of the tube or flask. The whey is clear with a small, white, flocculent deposit. The changes in the milk are accompanied by an unpleasant odour.

The whey is acid, and a drop examined microscopically shows the presence of numerous large Gram-positive rods, but, typically, spores are not present.

The above reaction constitutes a positive test, and isolation of the bacteria in pure culture is not attempted.

Occasionally, the typical stormy fermentation is not produced, for some bacteria of the group cause clotting of the milk with less or no gas formation. In some cases the milk is digested and an offensive odour produced. A negative reaction is shown by the milk remaining unchanged.

As an alternative medium to milk, lactose broth can be used. The air is expelled from the medium by heat, and the inoculated tubes are heated to 80° C. for ten minutes. The development of acid and gas after subsequent incubation at 37° C. for twenty-four to forty-eight hours demonstrates the presence of spore-bearing bacteria, for all coliform and allied organisms would have been killed by the preliminary heating. Anaerobic incubation should be employed, otherwise the number of positive results is greatly reduced.

The results of the test are recorded as positive, atypical or negative, and expressed in the same way as in the case of *Bact. coli*, *e.g.*, "Positive in 100 c.c.; negative in 10 c.c.," and so on.

Wilson and Blair (1924, 1925) adapted their glucose-sulphite-iron agar medium to the quantitative estimation of *Cl. welchii* in water, and reported on it as being "particularly suitable for the determination of the number of *B. welchii* in a water supply." In this medium *Cl. welchii* develops as large black colonies, measuring from 3 mm. upwards in diameter. Black colonies, which are usually smaller, may also be produced by various other bacteria. To restrict the growth of these latter, Wilson (1938) suggested incubating the plates at 44° C., at which temperature *Cl. welchii* colonies still reach their usual size.

For routine work, however, it is hardly necessary to attempt an actual enumeration, and we prefer the simple milk test which shows either a positive or a negative result in a definite quantity of water. Wilson suspects faecal contamination if more than one large black colony develops from 40 c.c. of water, but in our experience a negative milk reaction in 100 c.c. of water is usual with most untreated waters regarded as satisfactory on other evidence.

Significance of Clostridial Spores in Water

The sporing anaerobes are often disregarded in the bacteriological examination of water, but we seldom omit the milk test, for long experience has convinced us of its value.

The regularity with which appreciable numbers of *Cl. welchii* and similar organisms occur in faeces, manure, sewage and filth is generally recognised. Pure waters, on the other hand, are free from these bacteria and their spores, even in so large a volume of water as 1,000 c.c., and, though initially impure waters may after adequate treatment occasionally give a positive milk reaction in 100 c.c., no naturally pure water should yield such a result without arousing suspicion.

The access of sewage or manure to a water supply introduces *Cl. welchii* as well as *Bact. coli*, and experience shows, as regards polluted waters, a fairly close correlation between the presence of *Bact. coli* and a positive milk test. The number of sporing anaerobes in faeces and sewage is much less than that of *Bact. coli*, and a similar ratio between Clostridial spores and *Bact. coli* is usually found in recently contaminated waters. Thus, by the time Clostridia are detectable in 100 c.c. of the water, *Bact. coli* would usually be found in such small volumes (1 c.c. or less) as readily to condemn the supply. We nevertheless regard the *Cl. welchii* test, in such cases, as constituting valuable support of the *Bact. coli* findings and as providing additional evidence of the unwholesome character of the contamination.

The milk test has its greatest value, however, in demonstrating a remote pollution which the coliform examination may fail to detect. On account of their high resistance, the Clostridial spores can survive in water long after the time of the pollution, and can thus persist when

all the other faecal bacteria have disappeared. A positive *Cl. welchii* reaction, in an untreated water which is free from coliform bacteria, would point, therefore, to old or intermittent contamination, and the water at the time of sampling would not necessarily be unwholesome, for the less resistant organisms of disease, such as *Bact. typhosum*, which might possibly have been introduced, would, like *Bact. coli*, have perished. This fact is sometimes advanced as an argument against the utility of the *Cl. welchii* test, but we consider that it is important to know the antecedents of a water supply beyond its immediate history, and also whether it is subject to intermittent contamination. Owing to increasing population and industry, pollution of water supplies often tends to increase, or to change from intermittent to continuous. In detecting pollution before it is sufficiently near to be dangerous, the *Cl. welchii* test may provide a valuable fore-warning, as the following experience shows :—

Several bore-holes in the Chalk in a certain district had yielded for years a water free from coliform bacteria and *Cl. welchii* in 100 c.c. Then the milk test became intermittently positive (accompanied by an occasional false presumptive coliform reaction). The alarm was given and measures of protection were installed, but a considerable period of time elapsed before *Bact. coli* appeared in the raw water.

Despite much official advice and repeated recommendations, there are still in this country some water supplies which for various reasons, economic and otherwise, are sampled and examined only at such infrequent intervals as quarterly or six-monthly. It may readily arise that such infrequent or chance sampling may give uniformly good *Bact. coli* results over many years, yet the supply be dangerously contaminated at intervals in between the samplings. While such inadequate supervision is to be strongly deprecated, the milk test tends in some degree to compensate for this laxity, and it may give a warning sign which should prevent undue confidence in the supply. The presence of Clostridial spores, in such cases, has in more than one instance provided an indication for a closer watch, with the result that more frequent examinations, or selected periods for sampling, *e.g.*, after heavy rainfall, have revealed contamination hitherto unsuspected.

The view has been advanced that the presence of spores of *Cl. welchii* in a water supply is simply an indication of dust contamination. We are not in agreement with this reasoning, but, even so, there is no justification for exposing water to such contamination as would not be tolerated in the case of food supplies. Water supplies should be handled and protected with the same degree of care and cleanliness as other articles of diet.

There is reason to believe that some members of the *Cl. welchii* group multiply outside the body, *e.g.*, in decaying animal and vegetable matter, and this property has been used as an argument against the value of the stormy fermentation test in water examination. It is, of course, essential to recognise the possibilities and limitations of the test in interpreting results, but, even if the origin is decaying organic matter

(and as a rule this is not true of the Clostridial spores which are found in water), it is as well to know that such matter does gain access to a supply, for such conditions, if not immediately dangerous, are undesirable and should be prevented if possible.

As regards treated waters, the *Cl. welchii* test has a certain, though somewhat limited, value. Efficient slow sand filtration removes the great majority of the Clostridia (and their spores), and a properly filtered water should only at infrequent intervals give rise to a positive milk test in 100 c.c. volumes. The following are the results of an investigation of a water before and after sand filtration at a rate of about 3,000,000 gallons per acre per day :—

	Raw Water.	Filtered Water.
Number of samples examined	50	50
Number giving a positive <i>Cl. welchii</i> (milk) reaction in 100 c.c.	37	5

Coagulation (or excess-lime treatment), followed by sedimentation and rapid filtration yields similar results.

Chlorine, in the doses used in waterworks practice, does not destroy spores, hence the milk test is of no value in assessing the efficiency of chlorination. As applied to samples of chlorinated water, the *Cl. welchii* test may, however, reveal conditions in the water prior to chlorination and thereby indicate deficiencies in the filtration process or other preliminary safeguards.

The presence in river waters of trade waste or, in other cases, of minute traces of metals, such as copper, etc. (see p. 455), may so interfere with the recovery of *Bact. coli* in the examination of samples, that a fair opinion as to the extent of pollution is not obtained by the *Bact. coli* findings. The *Cl. welchii* test affords help in such cases, as the spores are not usually affected.

We have found the stormy fermentation test to be of valuable assistance. It is especially useful to bacteriologists who are called upon to examine varied and often unknown waters, for the complete information of a field survey cannot always be obtained. It may be a very useful auxiliary or confirmatory test to the *Bact. coli* examination.

References

- LARNER. 1922. *J. Amer. Med. Assoc.*, 78, 276.
 MEDICAL RESEARCH COMMITTEE REPORTS. 1919. Reports Nos. 12 and 39.
 MEDICAL RESEARCH COUNCIL. 1929. *System of Bacteriology*, Vol. 3, 1940. *War Memo. No. 2*.
 TOPLEY and WILSON. 1929. *The Principles of Bacteriology and Immunity*.
 WILSON and BLAIR. 1924. *J. Path. Bact.*, 27, 119.
 WILSON and BLAIR. 1925. *J. Hyg. Camb.*, 24, 111.
 WILSON, W. J. 1938. *J. Hyg. Camb.*, 38, 507.

CHAPTER XXXII

SPIROCHÆTES IN WATER

THE spirochætes form a group of micro-organisms closely similar to the true bacteria. Several classes are distinguishable on morphological grounds, but all are characterised by the power of movement, though, unlike the motile bacteria, spirochætes possess no flagella.

The varieties found in water are, with few exceptions, harmless saprophytes, but there are certain species which are pathogenic to man and give rise to such diseases as syphilis, relapsing fever and Weil's disease. The last is of interest as regards water, especially that of bathing pools, for the organisms can survive in slime and water and may gain entry to man not only by the mouth and nose, but also through the conjunctiva or an abrasion of the skin. The spirochæte causing Weil's disease is known as *Leptospira icterohæmorrhagiæ*, and the illness is characterised by fever, muscular pains, jaundice (usually), albuminuria and hæmorrhages. The organisms are excreted in the urine.

The disease was common among troops occupying wet and rat-infested trenches during the war of 1914-18, and in civilian life it appears from time to time among sewer workers and coal miners. Rats (and water) are usually implicated in the spread of the disease. Pathogenic leptospiræ have frequently been isolated from rats, and are excreted in the animal's urine; the majority of rats associated with sewers appear to harbour the organism (Stuart, 1939).

Field-mice in Japan and pigs and cattle in Australasia carry similar leptospiræ pathogenic to man. Dogs may also suffer leptospiral disease.

Sites polluted by the urine of infected animals (and men) are thus a source of danger, and investigations (Buchanan, 1924) into the cause of an outbreak of the disease among coal miners led to the discovery of virulent leptospiræ in the roof-slime of the mines. A factor common to four proved cases of Weil's disease was found by Robertson (1938) to be bathing, etc., in a rat-infested river. Houston (1926) investigated the spirochætes present in water, and on one occasion recovered pathogenic leptospiræ from a well water.

Spirochætes morphologically indistinguishable from *L. icterohæmorrhagiæ* have been found by workers in many parts of the world to be widely distributed in mud, slime and water from lakes, rivers and wells. Hindle (1925) drew attention to their presence in London water, and Houston (1926) confirmed this in an extensive series of observations. He found them not only in raw river water, but also in filtered water (they can pass through sand filters and Berkefeld filters) and unpolluted well water. Animal experiments carried out by Okell at the Wellcome Laboratories showed that, except on one occasion, the leptospiræ isolated by Houston from London waters were uniformly non-patho-

genic. Chlorination was found by Houston to be invariably effective in destroying the spirochætes, and the dose of chlorine was no greater than that required to kill *Bact. coli* and the other non-sporing bacteria.

The saprophytic water organisms are known as *Leptospira biflexa*, and their exact relationship to the pathogenic *L. icterohæmorrhagiæ* is somewhat uncertain. The latter was found by Buchanan to remain alive for long periods in slime and water, and it has been shown by Okell and others that avirulent types may become pathogenic after passage through animals. Topley and Wilson (1936) advise caution in accepting the latter evidence, since animals not infrequently act as leptospiral carriers, and the virulent strain may have arisen from the animal rather than from the saprophyte inoculated.

The suggestion has been made that *L. biflexa* and *L. icterohæmorrhagiæ* are the same organism, the virulence of the former having been temporarily lost by sojourn outside the animal body. The balance of evidence, however, is against this view, and a definite serological distinction is reported. The comparative infrequency, except under certain war conditions, of Weil's disease in man, despite the widespread natural distribution of *L. biflexa*, and the fact that cases of the disease can usually be traced to rats harbouring *L. icterohæmorrhagiæ*, would appear to confirm the experimental distinction.

It seems justifiable, on the evidence available, to regard the ordinary water leptospiræ as generally harmless, and to direct no special measures for their removal from water supplies. Prevention of Weil's disease is best attained by measures directed against the specific organism in animals, particularly the rat, and in man when infected.

In Weil's disease, as also in plague and other diseases, the rat is a permanent danger to man, and it is significant that, whenever outbreaks have occurred, rats have been incriminated, and the subsequent measures of disinfection have been followed by freedom from the disease.

Houston's study (1926) of the subject led him to express the following advice:—

"Recent experiences seem to point . . . to the desirability of avoiding 'dead-ends' in a water system, of taking water for drinking purposes direct from the main, and of having cisterns kept clean, covered and inaccessible to rat pollutions. . . . All will agree on the desirability of an extensive campaign against rats."

Swimming baths in which the water is used over and over again, and in which slime is apt to collect, are potential sources of infection, and in view of the fact that leptospiræ are able to pass through sand filters, chlorination is advisable in all such cases.

Characters of *Leptospira*. The leptospira is a comparatively long spiral organism. Considerable variation in length is seen, but 5 to 10 μ is about the average. The spirals are closely wound and the ends of the organism frequently appear hooked.

During movement, which may take place either forwards or backwards, various rapidly changing forms are seen, owing to the appearance and disappearance of secondary curves along the organism. Clumping

of the spirochætes tends to occur. Observation is best made by dark-ground illumination.

Spirochætes as a group are difficult to stain and to cultivate in the laboratory, but culture of the leptospiræ is not unduly difficult in liquid media. They are very sensitive to acidity (optimum pH 7.6) and common salt, and for good results, Fletcher's medium is recommended (see Appendix).

Incubation is carried out at 25° C.

It was found by Hindle (1925) that the multiplication of *L. biflexa* in water was encouraged by the addition of fæces, and Houston successfully used this method in his work on the London waters.

A piece of human fæces about the size of a pea is emulsified in 20 c.c. of the water under examination, and the whole incubated at 25° C. Microscopical examination, with dark-ground illumination, is made after ten days or so, and Houston found that if a negative result was obtained in twenty days it was useless to proceed. Growth takes place aerobically.

Human fæces is not always favourable to leptospiral multiplication in water in the laboratory, probably owing to the presence of bile, or incorrect reaction.

In view of the frequent presence of harmless leptospiræ in water, great care must be taken in the investigation of an outbreak of Weil's disease, before blame is levelled at the water supply.

The tests by which *L. biflexa* and *L. icterohæmorrhagiæ* are distinguished from one another are:—

1. The high pathogenicity of the latter to guinea-pigs.
2. The adhesion test of Brown and Davis (1927).

This test consists in mixing the suspected leptospiræ with leptospiral antiserum, and adding a suspension of bacteria such as *Bact. coli*. It is found that when in the presence of the leptospira and its specific antiserum, the bacteria adhere to the spirochætes in clumps. Thus, using a serum prepared against *L. icterohæmorrhagiæ*, a positive adhesion result is obtained only with *L. icterohæmorrhagiæ*, and not with *L. biflexa*.

Resistance of Leptospira. Leptospiræ are readily destroyed by heat and cannot withstand 55° C. for half an hour. They are sensitive to minor degrees of acidity, and are readily killed in water by chlorination.

The small dose of chlorine required to kill *Bact. coli* was found by Houston equally effective in the destruction of leptospiræ.

References

- BROWN and DAVIS. 1927. *Brit. Journ. Expt. Path.*, VIII., 397.
BUCHANAN. 1924. *Brit. Med. Journ.*, II., 990.
HINDLE. 1925. *Ibid.*, II., 57.
HOUSTON. 1926. 20th Annual Report to Metropolitan Water Board.
ROBERTSON. 1938. *Brit. Med. Jour.*, II., 1300.
STUART. 1939. *Ibid.*, I., 324.
TOPLEY and WILSON. 1936. "The Principles of Bacteriology and Immunity."

CHAPTER XXXIII

PATHOGENIC ORGANISMS IN WATER

(1) TYPHOID AND PARATYPHOID BACTERIA

ENTERIC fever is a disease of man, and it is therefore essentially from human, and not animal, excreta that typhoid and paratyphoid bacteria may gain access to water, and cause disease among the consumers.

These bacteria multiply in the human body and are excreted in countless millions by sufferers from enteric fever. Amongst the population, however, there also exists a small proportion of apparently healthy individuals who may, or may not, have suffered in earlier life from enteric fever, but who nevertheless excrete in the faeces or urine, continuously or intermittently, large numbers of typhoid or paratyphoid bacteria. These so-called *carriers*, many of whom remain unidentified, perpetuate the disease, functioning as the reservoirs of the infecting organisms, and they are responsible for most of the cases of the disease which now arise.

Sewage therefore may, and probably usually does, contain small numbers of the enteric organisms, even in the absence of cases of the disease amongst the community. *Bact. typhosum* was isolated from the sewage of Belfast by Wilson (1928), and *Bact. paratyphosum* B was obtained from samples of Edinburgh sewage by Gray (1929) and Begbie and Gibson (1930). Houston (1930) recovered *Bact. typhosum* from 0.1 c.c. of the crude sewage of London at the Barking outfall, and in 1931 Wilson and Blair reported that over a period of two years they had almost constantly found *Bact. typhosum* in 1 c.c. volumes of Belfast sewage, that *Bact. paratyphosum* was also present on two occasions, and that both organisms had been isolated from sewage-polluted river water. These findings were obtained at times when there were few, or no, detectable cases of the disease, and in more recent years similar results have been reported from many parts of the world. The effect of an epidemic is well illustrated by the following :

After an outbreak in which 233 cases of paratyphoid fever occurred at Epping during February and March of 1931, the sewage of that town was shown (Houston, 1931) to contain an average of 312 paratyphoid bacteria per c.c., and the sewage effluent (after land treatment) 57 per c.c. It was also calculated that, during the epidemic, Cobbins Brook, which received part of the effluent, had been contaminated with 33,000 million paratyphoid bacteria per day's flow. The persistence of these pathogens in the Epping sewage and effluent has been noted in the subsequent Reports to the Metropolitan Water Board (1932-38), the respective averages for 1938 being 271 and 8.1 per c.c. It is noteworthy that, despite these high figures, the numbers

of *Bact. coli* in the sewage (and effluent) have generally been at least several hundred times that of the pathogens. Since the commencement of the outbreak, the effluent has been continuously chlorinated.

Our own experience is in agreement with the results recorded above, and we have isolated *Bact. typhosum* and *Bact. paratyphosum* B from various samples of sewage, sewage effluent and river water. Thus, we had no difficulty in obtaining *Bact. typhosum* from the Croydon sewage during the outbreak of typhoid fever in that town in 1937, and in 1941 we could still recover the organism from 1 c.c. of the crude sewage.

Many widespread outbreaks of enteric fever, resulting in much serious illness and loss of life, have been caused by sewage-polluted water, and in many of the so-called "milk-spread" epidemics the contamination of the milk has been shown to be due to the use of infected water for washing the milk utensils. The pre-eminent importance of pure water in the prevention of typhoid fever was emphasised by Sir George Newman who, when Chief Medical Officer to the Ministry of Health, wrote :—

" While polluted water has often been used by individuals with impunity the question of its importance in relation to health and disease came to be more fully recognised as the relation of uncleanness to disease came to be understood and public water supplies were introduced. Formerly a sporadic case of disease or death due to drinking contaminated water was not recognised, but when epidemic disease followed the wide distribution of water supply, attention was drawn to the importance of its purity in regard to the health of communities. For instance, Corfield collected particulars of more than 50 water-borne epidemics of typhoid fever between 1864 and 1902, and we now know that the first of preventive methods is to secure for a community a sufficient and wholesome water supply. ' Among the circumstances which we find associated in outbreaks of typhoid fever,' wrote Sir John Simon in 1869, ' there is none of more frequent occurrence, none which we are more entitled to consider directly causative of the disease, than the consumption of polluted water. It has been one of our most familiar experiences that excremental fouling of wells is, in this respect, among the worst dangers which can threaten the health of the community.' Some typhoid outbreaks have been traced to pollution of shallow wells, as at Guildford in 1867, in the Uxbridge Rural District in 1882, at Hitchin in 1883, at Beverley in 1884, and so on; others have been due to pollution of deep wells, as at Caterham in 1879, or at Watling in 1893 (1,315 cases). Other outbreaks have been due to pollution at the springs, as at Maidstone in 1897 (1,847 cases); or pollution of streams and rivers, as in the Tees Valley in 1890, at King's Lynn in 1892, at Lincoln in 1905 (900 cases), or, again, contamination of the ground water, as at Munich, at Terling, in Essex, in 1867, and at various places in America, or once more, to pollution of the water in the mains, as in the famous case of Caius College, Cambridge, in 1873. The illustrations are innumerable, the devastations in the early years of public supplies extensive; a polluted supply brought disease, a pure supply brought health. ' Many of the public improvements have coincided with the reduction of typhoid,' wrote Sir George Buchanan as long ago as 1866. ' Though not with absolute constancy, drying of the soil of a town and reduction in the crowding of houses have been followed by reduction of fever. Much more important appears to be the substitution of an ample supply of good water for a scanty and impure supply; other things being equal, the towns in which this substitution has been completed

have made most improvement.' The improvement has occurred in the reduction of cholera, epidemic diarrhoea and dysentery, as well as typhoid; the deaths from typhoid have declined from 370 per million in 1875 to 12 per million in 1924. Effective supervision of water supplies includes control of the sources, gathering grounds and catchment areas, of methods of filtration and storage, and of distribution adits and house cisterns and to this end topographical, bacteriological and chemical examinations should be made regularly of all public water supplies. Happily there is now widespread recognition of this primary public health requirement, a wholesome and sufficient water supply."

While water has played a major part in the spread of enteric fever in the past, the specific contamination of foodstuffs by carriers, flies, etc., has also to be considered, and has received much attention in recent legislation. Though carriers constitute the major problem in all respects, flies are considered dangerous as vehicles conveying enteric organisms from faeces to food, especially where rural methods of sanitation permit access of flies to faeces, and gulls may play a similar, though less important, rôle as regards water. It may be said that the disease could be almost entirely eradicated by the absolute protection of foodstuffs, including particularly water, from excremental contamination.

The decline of enteric fever in Great Britain in recent years constitutes one of the triumphs of preventive medicine, and whilst it has been due largely to general improvements in sanitation, sewage disposal, etc., the provision of pure and abundant water supplies has played no mean part in this advance. Sanitary control is now extremely efficient, and water purification has reached a high standard of excellence, but the occasional occurrence of quite serious outbreaks shows the need for still greater efforts at improvement, together with the dangers attaching to any temporary relaxation of precautions.

The problem of the carrier has still to be solved, for no uniformly successful method of curing this condition has yet been devised. Occupational restrictions and careful instruction of the carrier as regards strict personal hygiene can reduce this danger to small proportions. Besides being prevented from handling food for others, carriers should not be employed on a waterworks, or knowingly admitted thereto.

Distribution and Viability

The enteric organisms are never found in nature, *e.g.* in sewage, soil, water, shellfish, milk, vegetables, etc., except in the presence, immediate or fairly recent, of a case or carrier of the disease. None of the lower animals is known to suffer from the disease or to harbour typhoid or paratyphoid bacteria, and the organisms do not normally multiply or survive for long outside the human body.

When present in, for example, sewage or water, the typhoid and paratyphoid bacteria are more delicate and decadent organisms than *Bact. coli*, which generally outnumbers them by at least several hundred times. These facts endow *Bact. coli* with great importance as an indicator of potentially dangerous pollution, and the absence of this

bacterium from water usually justifies the assumption that the water is free from enteric organisms. An exception to this is possible in the case of pollution of water by the urine, and not faeces, of an enteric patient or carrier, for the urine may be swarming with enteric organisms and yet contain no coliform bacteria. A small amount, *e.g.*, a few drops, of infected urine could dangerously infect such a large volume of water as several million gallons.

There is unanimity of opinion, however, that conditions outside the human body are unfavourable to the typhoid and paratyphoid bacteria. They are therefore only sparsely distributed in nature, and it is unlikely that they are ever present in anything but comparatively small numbers in water, even when subject to habitual sewage pollution. After prolonged research, Houston (1913) came to the conclusion that *Bact. typhosum* could not be uniformly present in 10 c.c. of the River Thames water at the waterworks intakes. This quantity of raw Thames water would contain an average of over 400 excretal organisms.

The period of time, after being voided by the human body, during which the enteric bacteria can survive in faeces, sewage, soil and water is a point of great importance, and the length of storage required to cause the practical disappearance of any typhoid bacteria which may gain access to a source of water supply has on many occasions received consideration by Parliamentary Committees. Precise times cannot be stated, and only relatively wide limits can be estimated, differing possibly in every individual case. Survival is influenced by many factors, *e.g.* :—

- (a) The character of the containing material,
- (b) The presence of other bacteria, phages, protozoa, etc.,
- (c) Temperature,
- (d) The presence of bactericidal agents or substances.

The enteric organisms succumb more readily when in the presence of other bacteria and higher forms of microscopic life. Sunshine is also particularly destructive, whilst survival is considerably prolonged by low temperatures. The latter effect is probably due to the lessened activity, under cold conditions, of antagonistic forms of microbial life.

As regards water, a most extensive study was made by Houston (1908-14) of the viability of *Bact. typhosum* in raw river water (Thames, Lee, New River). In his earliest experiments (1908) he used a number of typhosum strains, all of which had been grown on artificial media and which he termed "cultivated." The number of typhoid bacteria added to the water samples varied from 40 per c.c. to 8,000,000 per c.c. (average about 1,000,000 per c.c. in the total eighteen experiments), and bottles of the infected water were kept in a dark cupboard of the laboratory, the temperature varying between 10° C. and 21° C. He found that a period of five to nine weeks' storage was required to effect practical destruction of the pathogens (failure to isolate them from 100 c.c. of the water), the time varying roughly according to the numbers added, but he was able to show that in all cases a 99.9 per cent.

reduction occurred by the end of the first week. Similar experiments (1910) conducted with "uncultivated" *Bact. typhosum* (the infected urine of a typhoid carrier was used) showed an equally rapid decline in the first week and the final result was usually obtained in three weeks, sometimes sooner. The difference in the viability of cultivated and uncultivated *Bact. typhosum* was confirmed (1911) by using the same strain (obtained from the urine of another carrier) before and after growth on laboratory media.

Houston (1911) also investigated the effect of temperature on the viability of cultivated *Bact. typhosum* in river water. Bottles of the water were inoculated with an average of 100,000 organisms per c.c. and were thereafter stored in the dark at various temperatures from 0° C. to 37° C. The results were striking, *e.g.*, two weeks sufficed for the organisms to become absent from 1 c.c. of the sample stored at 37° C., whereas 4, 5 and 9 weeks were required to obtain the same result with the samples stored at 18° C., 10° C. and 0° C. respectively.

Numerous laboratory experiments have been recorded concerning the period of survival of *Bact. typhosum* in water and sewage, but, due to the use of different bacterial strains, different laboratory technique and media, and to the influence of the factors already noted, results of a most conflicting character have appeared. Our own experimental results are in general agreement with those of Houston, especially with regard to the sudden initial decrease of *Bact. typhosum* in polluted waters similar to the River Thames.

We have found no significant difference in the behaviour of *Bact. paratyphosum* B in water as compared with *Bact. typhosum*. In recent experiments employing cultivated strains and adding smaller numbers than Houston (5 per c.c.) to samples of river waters, such as are used, after purification, for public supply purposes, we have found both organisms to decrease greatly in the first four days and become absent from 1 litre after 3 weeks' storage in the dark at 10°-15° C. Identical experiments carried out in parallel with a typical hard pure Chalk water showed, however, striking differences. In this case neither organism showed any significant diminution in number in the first week of storage, and both were still present in 10 c.c. after two weeks. A period of four weeks was required before a negative result in 1 litre was obtained.

Our experiments confirm the view that the survival of enteric organisms is more prolonged in pure water than in impure water. This point is of great practical importance. Pollution of pure or purified waters at waterworks, in service reservoirs, or in mains, is thus particularly dangerous, and the most stringent precautions are required to protect water prepared for delivery to consumers.

There is reason to believe that enteric bacteria gaining access to water direct from infected sewage generally perish in a shorter time than laboratory researches indicate. In a series of experiments whereby typhoid-infected water was enclosed in permeable sacs submerged in flowing river water and lake water, so that complete diffusion of soluble

substances was possible without allowing escape of the pathogens, Jordan, Russell and Zeit (1904) found initial numbers of 500 to 2,000,000 per c.c. to decline rapidly so that by the third to the eighth day no organisms could be recovered from 5 c.c. of the water.

Excluding accidental specific pollution of pure water, it is generally accepted that, under the conditions prevailing in this country as regards waters (*e.g.*, rivers, etc.) to which sewage normally gains access, 99 per cent. of typhoid bacteria die in less than five days, and 99.9 per cent. in seven days. In other words, storage for five days improves the water in this respect one hundred times, and seven days' storage one thousand times.

We have no reason to believe that the paratyphoid bacteria possess any greater resistance than *Bact. typhosum* to adverse conditions in water. Of all these organisms there would seem to be (as Houston said of *Bact. typhosum*) "a few specially resistant bacilli, sometimes described as the 'resistant minority,'" which can persist for several weeks, and which may be of more significance in public health than their numerically superior, but less viable, associates.

Prolonged storage of water in order to bring about the destruction of the enteric organisms is no longer essential owing to the present-day efficiency of chlorination. This method effects in hours a bacterial destruction equivalent to that resulting from weeks of storage.

The bacteriology of fæces, sewage and soil is closely related to that of water, and the factors influencing the longevity of the enteric organisms in water operate also in these environments, often in greater degree, owing to the more extensive and varied biological populations. Harvey (1915) made observations on the numbers of *Bact. typhosum* in specimens of fæces from carriers, and found that the bacteria survived for a period of four months in cold weather. The period of survival in fæces and soil in hot weather, however, did not exceed two weeks. As regards *Bact. paratyphosum* B, Fletcher (1917, 1918) found that these bacteria could be cultivated from fæces for four days at 37° C., and for ten days at 15° C.

The researches made by Gray (1929) on the presence of *Bact. paratyphosum* B in the sewage of Edinburgh demonstrated a very rapid death of the organism in that material. Thus, out of twenty specimens of sewage he succeeded in isolating *Bact. paratyphosum* B from seven on the day of collection, but re-examination of the specimens one, two and four days after collection all gave negative results. Such results are not general with enteric bacteria. For instance, from an "average" sample of crude domestic sewage in which we found *Bact. typhosum* to be present, this organism was repeatedly isolated during storage of the sample in the dark at room temperature (10°-15° C.) up to the fourteenth day after collection. Wilson and Blair (1931) stored samples of Belfast sewage in Winchester quart bottles exposed to light and at room temperature, and succeeded in recovering *Bact. typhosum* after thirty-eight days. They observed that the bacteria seemed to disappear from the supernatant liquor and to survive in the sediment.

Other workers had previously shown that the survival of *Bact. typhosum* in sewage was favoured by envelopment of the bacteria by particulate matter, *e.g.*, faeces. Ruchhoft (1934) reports the survival of cultivated *Bact. typhosum* in stored activated sludge for periods of 8-14 days, and, in one case where the temperature was lowered to 10°-15° C., survival was prolonged to 83 days.

In addition to such factors as sunlight and temperature, the composition of sewage in respect of the presence of disinfectants in trade-wastes, etc., has an important bearing on the survival of pathogens therein.

As previously indicated, enteric bacteria are not necessarily removed or destroyed at sewage purification and disposal works, and the effluents should always be regarded as potentially dangerous.

Though laboratory results may appear to be rather conflicting, there is now sufficient evidence to confirm the epidemiological conclusions, arrived at long ago, that the enteric organisms can survive outside the human body sufficiently long to cause water-borne disease, and the period of their survival can be said to vary according to circumstances from five days to five months. In the tropics, death appears to take place more quickly than in temperate zones.

Characters of *Bact. typhosum*

Morphology. Actively motile, non-encapsulated, non-sporing rods, usually about 3μ in length and 0.5μ in breadth, but long, wavy, filamentous forms, 20-30 μ in length, may be seen in urine and cultures. They are easily stained, being Gram-negative and non-acid-fast.

Cultivation. Growth readily occurs on ordinary laboratory media, the optimum conditions being an aerobic atmosphere, blood heat, and a neutral reaction (*pH* about 7). Cultivation on agar slopes produces a profuse, confluent and easily emulsifiable growth with no coloration of the medium. On agar plates, both smooth and rough colonies (see p. 453) may develop, most usually the former. Both forms are colourless, the smooth colonies being similar to those of *Bact. coli* but smaller and more transparent. The rough colonies, like those of *Bact. coli*, are dull, flat, and irregular in outline and surface. These latter agglutinate spontaneously in normal saline. Similar appearances are observed on gelatin media and liquefaction does not occur. In broth, a uniform turbidity is produced by the smooth forms, but the rough variety give rise to a deposit.

Neutral-red bile-salt lactose agar (MacConkey agar) is a good differential medium. Growth of *Bact. typhosum* on this causes no reddening of the medium and the (smooth) colonies are round, domed, clear and colourless or slightly amber. They are thus readily distinguished from the red colonies of *Bact. coli* and the other coliform bacteria.

The bismuth sulphite medium of Wilson and Blair (see Appendix) is of merit both as a differential and as a selective medium, but it is somewhat difficult of preparation and standardisation. *Bact. typhosum* produces flat, dry, black colonies surrounded by a brown-black halo

showing a metallic sheen, and the growth of coliform bacteria is almost completely inhibited. The presence of bismuth prevents the development of *Cl. welchii*.

Other recommended selective and differential media for the isolation of *Bact. typhosum* from mixed cultures include tetrathionate broth, brilliant green broth, brilliant green eosin agar (Jones, 1936), and Endo agar.

Biochemical Reactions. *Bact. typhosum* has very little fermentative power and produces no gas from any carbohydrate. Acid is formed in glucose, laevulose, galactose, maltose, dextrin, xylose, mannitol and sorbitol, but not in lactose, sucrose, arabinose, rhamnose or dulcitol. The inability of *Bact. typhosum* to produce acid from lactose forms the basis of such differential media as those of MacConkey, Endo, etc.

Litmus milk is left practically unchanged, and indole is not produced from peptone water.

Serological Reactions. The serum of persons suffering from typhoid fever develops substances ("agglutinins") which are not normally present. If such "immune" serum be diluted and a drop mixed on a slide with a drop of a broth culture of *Bact. typhosum*, the bacteria can be seen (under the microscope) first to lose their motility and then to adhere together in clumps. This phenomenon is called "agglutination," and it is significant that the serum, if sufficiently diluted, will affect *Bact. typhosum* but no other bacteria, *i.e.*, the reaction is specific for *Bact. typhosum*. This is utilised both in the diagnosis of the disease and in the recognition of bacteria, and is the final step in the identification of *Bact. typhosum*. Similar phenomena occur in the case of the paratyphoid and food-poisoning bacteria.

Resistance and Viability. These properties have already been discussed in certain respects. *Bact. typhosum* is readily killed by heat and disinfectants. Heating to 60° C. for 30 minutes destroys it, and it is immediately killed by boiling.

Bact. typhosum is at least as susceptible to destruction by chlorine as *Bact. coli*, and it can safely be assumed that if water is so chlorinated that *Bact. coli* is destroyed, *Bact. typhosum*, if present, would also be destroyed. Chlorination provides the most certain, ready and economical method of preventing the spread of typhoid fever by polluted water, was extensively used with great success by the military forces during the war of 1914-18, and is in widespread use to-day in both civil and military practice.

The Paratyphoid Bacteria

The paratyphoid bacteria closely resemble *Bact. typhosum* and produce a similar, though milder, disease in man. The facts regarding their distribution and viability in nature are (as already indicated) similar to those of *Bact. typhosum*, and outbreaks of paratyphoid fever, though usually due to infection of foodstuffs, such as milk, etc., may be caused by excretal pollution of water supplies. The paratyphoid bacteria resemble *Bact. typhosum* in their morphology, staining reactions and

cultural appearances, but differ from it, and among themselves, in their biochemical and serological reactions.

Two distinct types are recognised, *Bact. paratyphosum* B, the common variety in this country, and *Bact. paratyphosum* A, which is seldom found in Western Europe but occurs more often in the East. A third variety, *Bact. paratyphosum* C, has also been described as causing enteric fever in man, but it appears to be very rare.

The paratyphoid bacteria resemble *Bact. typhosum* and *Bact. dysenteriae* in not fermenting lactose, but differ from these organisms in producing acid and gas in glucose and other carbohydrate media. Apart from their serological reactions, the paratyphoid bacteria are distinguished from *Bact. typhosum* by their ability to produce gas as well as acidity in glucose, maltose, arabinose, rhamnose, mannitol and dulcitol. As compared with *Bact. paratyphosum* A, *Bact. paratyphosum* B produces acid and gas more actively and has the distinguishing properties of fermenting xylose and of turning litmus milk alkaline.

None of the paratyphoid bacteria forms indole in peptone water, and this provides a convenient early means of distinguishing them from the Paracolon group (termed "Paratyphoid-B-like" by the German writers), certain members of which give identical fermentation reactions.

As with *Bact. typhosum*, there are specific serological tests for each of the paratyphoid types.

(2) THE SALMONELLA (OR FOOD-POISONING) BACTERIA

In its most limited sense, the *Salmonella* group of bacteria comprises a large number of types which are distinguished from the paratyphoid bacteria, solely or essentially, by their serological reactions. Many authorities, however, include *Bact. paratyphosum* (and even *Bact. typhosum*) under the heading of *Salmonella*, and the serology of these organisms provides good reason for so doing. There is, on the other hand, a fairly well-marked clinical distinction between enteric fever and bacterial food poisoning, and we find it more convenient to regard the enteric organisms separately from the *Salmonella* bacteria.

The commonest members of the group (in this narrow sense) are *Bact. aertrycke*, *Bact. enteritidis* and *Bact. suipestifer*. These organisms have been responsible for many of the outbreaks of "food-poisoning" in man. Foodstuffs, both animal and vegetable, have generally been shown to be responsible, and water has not, to our knowledge, been incriminated as a vehicle of infection.

Some of the members of the group appear to live harmlessly in the intestines of animals, and are consequently found in their excreta. While chronic human carriers are seemingly very uncommon, it would appear that a temporary carrier state may occur in man.

Rodents often harbour these organisms, *Bact. enteritidis* and *Bact. aertrycke* being the commonest types in rats and mice. Less frequently, rabbits may play a similar rôle, and it also appears that the organisms may be harboured by apparently healthy pigs. Doubts

have existed concerning the normal occurrence of these bacteria in the intestines of cattle, horses and sheep, although these animals are admittedly prone to Salmonella diseases, but in connection with the Wilton outbreak of food-poisoning (Ministry of Health, 1938), in which raw milk was proved to be the vehicle of infection, the causative Salmonella type (Dublin) was repeatedly isolated from the dung of an apparently healthy cow.

It would seem reasonable to suppose that water could be infected with Salmonella organisms by the access to it of the excreta of these animals, or the dead animals themselves, as well as by faeces from, or sewage infected by, human cases (and carriers) of food-poisoning. Scott (1931) has, in point of fact, recovered Bact. aertrycke, Bact. enteritidis and other Salmonellas from the sewage of various towns in this country. There is as yet, however, no conclusive evidence of the isolation of the Salmonella bacteria (excluding the enteric organisms) from water.

Little is known regarding the viability of these organisms outside the animal body, but, according to White (1929), Bact. suipestifer has been isolated from dung after thirty-six days, and from carcasses up to 160 days. The Salmonellas can tolerate desiccation to a considerable degree. They may also persist for months in tap water or distilled water, but the number is said to decrease rapidly during the first week or ten days. Their longevity, like that of Bact. typhosum, is greater at low temperatures.

There is little information concerning the effect of chlorination on these bacteria, but it is likely that they are as susceptible as Bact. coli to destruction by chlorine, and the limited experiments we have made support this view.

Two Salmonella types were used, Bact. aertrycke (mutton) and Bact. enteritidis (National Type Cultures). Emulsions in sterile tap water were made from agar slope cultures and added to Winchester quart bottles of sterile tap water so that there resulted three dilutions as follows:

- | | | |
|-----|-------------------|-----------------------------------|
| (1) | 100 to | 1,000 bacteria per c.c. of water. |
| (2) | 1,000 to 10,000 | " " " " " |
| (3) | 10,000 to 100,000 | " " " " " |

These were chlorinated, using dilute sodium hypochlorite solution, so that the dose of chlorine was 0.25 parts per million. After 30 minutes there still remained 0.12 p.p.m. of free chlorine, and a trace was detectable at the end of an hour.

After thirty minutes' and one hour's contact, inoculations up to 100 c.c. of water were made into glucose broth. These were incubated for three days at 37° C. and remained sterile.

It is unlikely that other members of the group differ from Bact. aertrycke and Bact. enteritidis in their resistance to chlorine, and efficient chlorination would, therefore, appear to provide an adequate safeguard against possible water-borne Salmonella infection.

Some of the Salmonella bacteria attack, so far as is known, only animals or birds, e.g., Bact. abortus equi (mares), whilst others, e.g., Bact. aertrycke, Bact. enteritidis and Bact. suipestifer, cause disease

TABLE I
"TYPICAL" BIOCHEMICAL REACTIONS OF THE ENTERIC-SALMONELLA GROUP

Organism.	Lactose, Sucrose, Indole.	Glucose.	Mannitol.	Dulcitol.	Inositol.	Arab- inose.	Xylose.	Rham- nose.	Maltose.	Litmus milk. No clot.	
										1 day.	3-7 days.
Bact. typhosum .	—	A	A	—	—	—	A	—	A	A	Alk. Sl.
Bact. gallinarum .	—	A	A	— or A	—	A	— or A	— or A	A	A	Alk.
Bact. paratyphosum A.	—	AG	AG	AG Sl.	—	AG	—	AG	AG	—	A Sl.
Bact. pullorum .	—	AG	AG	—	—	AG	AG	AG	—	—	A Sl.
Bact. suipestifer .	—	AG	AG	—	—	—	AG	AG	AG	A	Alk.
Bact. enteritidis Gaertner											
Bact. dublin .	—										
Bact. newport .	—	AG	AG	AG	—	AG	AG	AG	AG	A	Alk.
Bact. stanley .											
Bact. dar-es-salaam											
Bact. abortus equi .											
Bact. paratyphosum B.											
Bact. aertrycke .	—	AG	AG	AG	AG*	AG	AG	AG	AG	A	Alk.
Bact. derby .											
Bact. morficans bovis	—	AG	AG	AG	AG	AG	AG	—	AG	A	Alk.
Bact. reading .	—	AG	AG	AG	AG	AG	AG	—	AG	A	Alk.

A = Acidity.

G = Gas.

Sl. = Slight.

Alk. = Alkalinity.

* Variable in case of Bact. paratyphosum B and Bact. aertrycke.

in animals, birds and man. The disease in man is characterised by an acute gastro-enteritis which usually subsides within a week; more serious cases infrequently occur but it is rare for Salmonella organisms (other than Bact. paratyphosum) to cause disease resembling enteric fever.

Characters of the Salmonella Bacteria

These bacteria resemble the enteric organisms in that they are Gram-negative, non-sporing, motile rods.

They grow on ordinary media, such as agar and gelatin, a neutral reaction and blood heat providing optimum conditions. The growths resemble that of *Bact. typhosum* and have no distinctive appearances. Gelatin is not liquefied, lactose and sucrose are not fermented, and indole is not formed in peptone water. Litmus milk becomes at first slightly acid, but later reverts to neutrality and then turns alkaline without clotting. In a few strains the reversion to neutrality and formation of alkalinity may not occur till after several weeks. All the known members of this group ferment glucose, and most of them ferment dulcitol with production of acid and gas, but in a few instances the fermentation is feeble.

It is to be noted, however, that absolute reliance should not be placed on fermentation reactions. As regards dulcitol, in particular, according to Bruce White (1929) some strains of *Bact. aertrycke* and *Bact. enteritidis*, and most strains of *Bact. suipestifer*, do not ferment dulcitol. Strains of these organisms are occasionally found which, on serological grounds, fall into a certain group, such as *Bact. aertrycke*, but which fail to give all the typical fermentation reactions.

Serological confirmation is essential for the inclusion of an organism in this group, and the aid of an expert in that work is required, for the task is one of considerable complexity.

(3) THE DYSENTERY BACTERIA

Dysentery in man may be caused by bacteria, of which there are several types, or by pathogenic protozoa, *e.g.*, *Entamoeba histolytica*. The latter does not normally occur in this country.

Bacterial dysentery, more common in the tropics than in temperate regions, is a diarrhoeal disease which, like typhoid fever, is liable to become epidemic where lack of sanitation prevails. Excretal pollution of water supplies is to be regarded as one mode of spread of the disease, but there is considerable evidence that flies play an important rôle in this respect. The bacteria are excreted in the faeces of persons suffering from the disease, and the carrier state may also arise. Both case and carrier form a danger to the community, carriers probably being responsible for most of the outbreaks which arise from time to time (*e.g.*, in mental hospitals) in this country.

Of the organisms generally admitted to cause bacterial dysentery, the commonest types in tropical countries are *Bact. dysenteriae* Flexner and *Bact. dysenteriae* Shiga. In this country the latter organism is of infrequent occurrence, but a third type, *Bact. dysenteriae* Sonne, has in recent years been the cause of a number of outbreaks and is apparently becoming almost as common as the Flexner type.

Various bacteria, including *Bact. dysenteriae*, *Bact. morgani*, *Bact. pyocyaneum* and *Proteus*, have been found at different times in the

stools of cases of "summer diarrhoea," a form of dysentery or infective enteritis particularly apt to attack infants.

Characters of the Dysentery Bacteria

As regards their morphology and cultural appearances, these bacteria are indistinguishable from the coli-typhoid group. They are thus Gram-negative, non-sporing rods which grow aerobically and do not liquefy gelatin. They are, however, non-motile and are essentially non-gas-producers in sugar media. They all cause acidity in glucose, and the same change is produced in a varying number of other carbohydrates and alcohols. Lactose is not affected by the Flexner and Shiga types, but other dysentery bacteria, *e.g.*, Sonne, form acid (often late) from this sugar. The Shiga type differs from Flexner and Sonne in not causing acidity in mannitol.

Indole production is variable in different types and is not altogether reliable as a differential criterion. Litmus milk is usually first acidified (without being clotted), and later neutrality or even alkalinity supervenes.

The cultural and biochemical reactions of the dysentery bacteria are not distinctive or stable, and serological tests are necessary for confirmation and differentiation.

TABLE II
BIOCHEMICAL REACTIONS OF DYSENTERY BACTERIA
Abridged from Topley and Wilson (1936)

Type.	Shiga.	Schmitz.	Flexner.	Alkalescens.*	Sonne.	Dispar.
Glucose .	A	A	A	A	A	A
Lactose .	—	—	—	—	A late	A late
Mannitol .	—	—	A	A	A	A
Dulcitol .	—	—	—	A	—	—
Litmus milk	Sl.A	Sl.A	Sl.A → Sl. Alk.	Alk.	A + late clot	A + late clot
Indole .	—	+	±	+	—	+
MR .	—	—	±	+	—	+
VP .	—	—	—	—	—	—
Citrate .	—	—	—	—	—	—

A = Acidity. Alk. = Alkalinity. Sl. = slight.

* There is considerable doubt whether *Bact. alkalescens* has any relationship to dysentery.

Viability and Resistance

The resistance of the dysentery bacteria is similar to that of the members of the coli-typhoid group. They are readily killed by heat and disinfectants.

Little information is available concerning their extra-intestinal

viability, but Dudgeon (1919) found in the Near East that the Shiga type could survive in *sterile* water for long periods (up to twenty-four days), especially when stored at a low temperature. Death would occur more speedily in natural and impure waters.

Experiments carried out in our laboratories with cultivated Flexner, Shiga and Morgan organisms show that the dysentery bacteria are readily destroyed by chlorine in doses such as are ordinarily used in the chlorination of water supplies. Chlorination efficiently carried out is a reliable method of treatment in the prevention of water-borne dysentery.

Bact. morgani

Bact. morgani, considered by some a causal organism of summer diarrhoea in children and of dysentery in adults, is a motile, Gram-negative, non-sporing rod which does not ferment lactose and produces acid with a little gas only in the hexoses. Under aerobic conditions it grows readily at 37° C. on the ordinary laboratory media. Alkalinity is produced in litmus milk, and indole is usually formed in peptone water. Gelatin is not liquefied.

Bact. morgani is a comparatively rare organism even in waters grossly polluted with sewage, and it is very unlikely that water plays any part in the causation of summer diarrhoea in children. The possible presence of this organism in water alleged to have caused diarrhoea should, however, be kept in mind.

The Search for Pathogenic Bacteria in Water

The examination of water for pathogenic organisms, such as the typhoid, paratyphoid and salmonella bacteria, is beset with difficulties and is seldom successful. The responsibility of water supplies for many epidemics of enteric fever is unquestioned, but is nevertheless based in most cases on circumstantial evidence. Whilst it is the rule in such cases to find evidence of sewage pollution (presence of *Bact. coli*, etc.), it is rare for the specific organisms to be actually isolated from the suspected water.

The reasons for this are many. The mass infection of the water with enteric bacteria necessary to give rise to an outbreak of the disease among the consumers is usually accidental and single rather than regular and repeated. Some two or three weeks may elapse between infection of the water and the appearance and diagnosis of the disease, and still more time passes before the water comes under suspicion and is examined. By this time the infected water has usually gone, or the specific organisms have died out. In such cases the best efforts are doomed to failure.

Even, however, if the pathogens are present, their numbers are as a rule very small, both absolutely, and as compared with the total bacterial content of the water. It is necessary, therefore, to examine large volumes of water (e.g., 1,000 c.c.) and at the same time prevent

the pathogens becoming overgrown by the more robust saprophytes. The technical difficulties are such that successful isolation, even in experienced hands, is to some extent a matter of chance and always a laborious procedure. The prospects of success are, however, much more favourable now than hitherto.

In the course of elaborate investigations carried out for years on raw River Thames water, Houston (1928) deliberately added typhoid bacteria to each of thirty-four samples to the average extent of 136 organisms per litre. Using the best methods then available, he recovered an average of only 28 *Bact. typhosum* per litre; that is, the examination elaborately performed by expert workers failed to reveal the presence of 80 per cent. of the pathogens added.

A negative finding in the search for enteric bacteria in a suspected water during an outbreak of enteric fever is not, therefore, to be accepted as significant, but the water must, on the other hand, be judged and convicted or acquitted on laboratory evidence of sewage pollution, the exclusion of other modes of spread of the disease, and a consideration of the characters and distribution of the epidemic. *Bact. coli* is by far the most delicate indicator of recent sewage pollution, and examination for this organism is the most important item, though, with improving bacteriological methods, the search for typhoid and paratyphoid bacteria is also worth attempting, and may be successful.

Many methods have been devised for the detection of typhoid and paratyphoid bacteria in water, but none can be considered completely satisfactory. The fact that large volumes of water must be examined renders the procedure cumbersome, but the chief difficulty rests with the accompanying bacteria, for no medium is so far available which will definitely promote the growth of enteric bacteria and at the same time reliably suppress *all* the saprophytes which may occur in water. By utilising various substances, *e.g.*, phenol, brilliant green, bismuth sulphite, and sodium tetrathionate, a number of selective and "enrichment" media have been elaborated which more or less completely inhibit the coliform bacteria and thus greatly facilitate the isolation of enteric organisms from faeces. Sewage and water, however, contain various non-lactose-fermenting saprophytes which can become "enriched" at least as well as the pathogens and which closely resemble the latter. Until the ideal medium is discovered, a successful issue is always somewhat uncertain and largely depends on skill, experience and assiduity.

To enable so large a volume of water as 1 litre to be examined, it has been customary to concentrate the bacteria by (1) precipitation with chemicals, *e.g.*, aluminium sulphate, followed by centrifugalisation or (2) filtration through a bacterial filter (Berkefeld, Seitz, etc.). Where either of these procedures is practicable it is to be recommended. Alternatively a concentrated liquid medium may be prepared for the reception of 1 litre of water.

In our experience, the bismuth sulphite agar medium of Wilson and Blair (or one of the modifications) offers the best chances of success.

As this is a solid medium, the best procedure is to concentrate the water so that the total inoculum can be spread over, or incorporated in, a small number of the plates. These are incubated for twenty-four to forty-eight hours, and all the black colonies which develop are picked off and subjected to further tests.

The original medium, even as modified by Wilson (1938), is somewhat complicated to prepare, and different batches are liable to behave erratically. By altering the concentrations of the ingredients, Tabet (1938) claims to have overcome the latter difficulty, but the mode of preparation is no simpler and we have not found this medium altogether satisfactory with some strains of *Bact. typhosum*, though it gives excellent results with paratyphoid bacteria. For general convenience, simplicity and reliability, the already-prepared "Difco" bismuth sulphite agar is to be recommended. When it is considered that none of these media can be stored but must be freshly made up for use, ease and simplicity of preparation offer substantial advantages.

The principle of the bismuth sulphite media depends (a) on the positive ability of the enteric (and salmonella) organisms to reduce a sulphite to a sulphide in the presence of glucose, and (b) on the inhibitory action of brilliant green and bismuth sulphite (in the presence of a certain excess of sodium sulphite) on the growth of *Bact. coli* and many other organisms. Provided they are not too overcrowded, the enteric organisms, growing on the surface of the medium, produce flat black colonies surrounded by a brown-black halo which gives a metallic sheen. Enteric colonies in the depth of the medium (*i.e.*, in "pour plates") are also black but the halo is usually lacking. Most other organisms do not grow or only develop as green colonies.

There are several important reservations to be made to the above remarks. In the first place, certain saprophytic organisms, *e.g.*, *Bact. aerogenes* and *Bact. effluviæ* (see p. 551), can develop as black colonies on this medium and may even produce a degree of halo. Secondly, for the enteric-salmonella group to produce typical metallic blackening, each colony must be well separated from its neighbours on the plate. Moreover, there appear to be some enteric strains which, even in the best of circumstances, develop only as green colonies. In practice, therefore, it becomes necessary to test suspicious green colonies in addition to the typical black ones. For these reasons, Tyagaraja (1940) questioned the advantage of the black pigmentation and has radically altered the composition of the medium so that the pathogens develop as green colonies whilst most other organisms do not grow at all. He has reintroduced, however, some of the complications of preparation, but claims that his medium is more stable. His published observations are confined to faeces and it remains to be seen what success is to be obtained with water (and sewage).

It is difficult to indicate with any degree of finality the best procedure to follow in the primary isolation of enteric organisms from water, but the following is put forward tentatively as the best method at present available.

TABLE III
THE GRAM-NEGATIVE NON-SPORING NON-LACTOSE-FERMENTING BACTERIA.
TYPICAL BIOCHEMICAL REACTIONS

Lactose —	
Glucose + (Acid only)	
Glucose — No Carbohydrates Fermented <i>Latmus Milk</i> , Alkaline <i>Bact. alcaligenes</i>	Mannitol — Motility —
	Indole — <i>Bact. dysenteriae</i> <i>Shiga</i>
	Indole + <i>Bact. dysenteriae</i> <i>Schmitz</i>
	Mannitol + (Acid only)
	Motility — Indole ± Sucrose ± Dulcitol — <i>Bact. dysenteriae</i> <i>Flexner</i>
	Motility + Indole — Sucrose — Dulcitol — <i>Bact. typhosum</i>
Glucose + (Acid + Gas)	
Mannitol + (Acid + Gas)	
Indole — Motility + Sucrose — Dulcitol ± <i>Bact. paratyphosum</i> A, B & <i>Bact. enteritidis</i> Gærtner <i>Bact. aertrycke</i> and the other <i>Salmonella</i> bacteria	
Indole + Motility + Sucrose — Dulcitol ± <i>Bact. paracoli</i>	
Gelatin — Sucrose — <i>Bact. morgani</i>	
Gelatin + Sucrose + <i>Proteus</i>	

The above reactions represent the preliminary stages in differentiating the commoner non-lactose-fermenting bacteria. Agglutination tests are essential for the final identification of the organisms indicated above in heavy type, as saprophytic bacteria may be biochemically indistinguishable. *Bact. dysenteriae* Sonne is omitted from the table as it produces acidity in lactose. It is otherwise biochemically similar to the *Flexner* type but is serologically distinct.

The sample should be packed in ice during transit, and the examination should be commenced with the minimum of delay. A quantity of $\frac{1}{2}$ to 1 litre is taken and aluminium sulphate and precipitated chalk (*e.g.*, 10 to 50 mg. of each per litre) are added to produce a floc. The whole is centrifuged at high speed to get as compact a deposit as possible.

The deposit is then dealt with in three ways: some is spread over plates of neutral-red bile-salt lactose agar, some over plates of "Difco" bismuth sulphite agar, and the remainder added to Kauffmann's tetrathionate broth (see Appendix). All are incubated at 37° C., and from the broth culture platings are made after one, two and three days' incubation on the same solid media as before.

The method is extravagant, but, in such examinations, much time, labour and material are always required. Also, a very large number of colonies may have to be picked off for investigation, *e.g.*, transparent non-lactose-fermenting colonies on the MacConkey agar, and typical black (together with any suspicious green) colonies on the bismuth sulphite plates.

The use of a few tubes of media for each colony will, however, readily exclude many bacteria from the group, and small tubes containing only 4 or 5 c.c. of medium will suffice. A suitable series is glucose, lactose, sucrose, mannitol, dulcitol and peptone water for indole-production, and it will be found that many bacteria ferment lactose or sucrose, produce indole, or fail to give acid (or acid and gas) in glucose or mannitol. In the event of any series giving the correct reactions as indicated in Table III, further investigation is required.

It must be remembered that freshly isolated bacteria are sometimes slow or atypical in their behaviour as regards motility, fermentative power and (especially) agglutinability. Several subcultures may be required to restore the typical reactions.

Serological confirmation requires much skill and care, and agglutination to approximately the titre of the serum should be obtained. The use of the mono-specific "H" and "O" sera, now available, has simplified this part of the procedure in eliminating the need for agglutinin-absorption tests. Controls must, of course, be included owing to the phenomenon, sometimes exhibited by bacteria, of spontaneous agglutination; and the fact, already mentioned, of the frequent in-agglutinability of recently isolated strains must also be borne in mind.

The procedure outlined above is suitable for the enteric organisms and the various members of the salmonella group, but, though the latter have been found in sewage, we have never isolated them from water, apart from experiments in which the organisms were first deliberately added. None of the types of *Bact. dysenteriae* grow on bismuth sulphite agar, hence, where attempts are made to recover these organisms, greatest reliance must be placed on the neutral-red bile-salt lactose plates, though there is some evidence to show that the Flexner and Sonne types are capable of developing in the presence of tetrathionate. Whether because of the lack of a suitable medium or for other reasons, there is, so far as we are aware, no recorded evidence of dysentery

bacteria having been isolated from water under natural conditions. Leifson (1935) reports improved results in the isolation of dysentery bacteria from faeces, by using a desoxycholate agar. This may prove of use with water, but we have so far had no opportunity of testing it.

Tetrathionate broth may be used in a concentrated form to eliminate the need for centrifuging the sample, and gives promising results. Szper (1935) modified Kauffmann's medium so that a litre of water could be directly added to 200 c.c. of a concentrated broth. Using this procedure, Szper added small numbers (1 to 5 organisms) of *Bact. typhosum* to samples of natural waters and recovered the organism from the artificially infected samples in from 35 to 65 per cent. of cases, while the natural samples gave 100 per cent. negative results. We have performed numerous experiments with Szper's and similar tetrathionate media, and have largely confirmed these results. The convenience of direct inoculation is obvious, and, if the enteric or salmonella organisms are present, the inhibition of coliform bacteria is almost complete. To permit concentration of the medium, Szper found it necessary to alter the proportions used by Kauffmann. Both media contain (besides nutrient broth) chalk, sodium tetrathionate, bile and brilliant green. In Szper's medium, after dilution with the sample, the concentration of tetrathionate is less than half that recommended in the original paper by Muller (1923), but this deficiency is compensated by the extra strength of brilliant green (1 : 25,000). We have obtained better results using Kauffmann's proportions, though to this end it is necessary to add the sample in the process of preparing the medium (see Appendix). We have not as yet, however, discovered a combination of ingredients which will suppress certain non-lactose-fermenters, and these, especially organisms biochemically resembling *Bact. morgani*, are apt to flourish in the medium and to complicate the subsequent isolation of the pathogens. *Proteus*, too, may on occasion cause similar difficulties. With natural waters, success—which may be striking—largely depends on the nature of the non-lactose-fermenting saprophytes present in the sample, and for this reason bismuth sulphite is still the better medium for recovering the enteric organisms from water.

Though the methods of search for pathogens in water still lack precision and contain many pitfalls, the coliform examination offers a considerable safeguard. Generally speaking, and apart from accidental (or deliberate) specific pollution of water in distribution, water supplies which naturally or after treatment are practically free from *Bact. coli*, can safely be considered innocent of spreading typhoid, salmonella or dysentery infection.

(4) *VIBRIO CHOLERÆ*

Except for an occasional imported case, cholera has been non-existent in this country for more than half a century, but, prior to that period, epidemics of the disease occurred from time to time and caused great loss of life. The disease is spread principally by the medium of

infected drinking water or food. Carriers play an important rôle in the spread of this disease as in others, and water is the most important vehicle of dissemination. An extensive epidemic due to infection of the water supply occurred in Hamburg in 1892. In the course of a few weeks no less than 18,000 persons in that city were attacked by the disease, and over 8,000 perished. Unfiltered water from the River Elbe was supplied to the inhabitants of Hamburg, and Koch isolated cholera vibrios from that water. It is instructive to note that the people of the adjoining district of Altona, whose water supply was from the same source but was efficiently sand-filtered before distribution, had no water-borne cholera, a striking example of the value of careful filtration.

Water derives its infection from the sewage or excreta of cases or carriers of the disease, and improved methods of sewage disposal, and protection and purification of water supplies are prominent among the sanitary measures which have prevented the disease from obtaining a foothold in recent years in this country.

Although many organisms closely resembling the cholera vibrio are found in soil, water, etc., it is probable that man alone perpetuates the disease, and that the cholera vibrio cannot long survive outside its human host.

Cholera vibrios infect the intestines of man and are excreted in the fæces of patients and carriers. The length of time during which they can survive in fæces, soil, water, etc., is governed by conditions similar to those concerning the enteric bacteria, namely sunshine, temperature, and the character of the accompanying microscopic life, etc. Under suitable conditions cholera vibrios may remain alive in fæces and soil up to about three weeks, but most will, under natural conditions, have perished before that time. Their period of survival in water is variable, being shorter in impure water than in pure, and in hot weather than in cold.

Houston (1913) examined stored raw river water (Thames, Lee and New) to which cultivated cholera vibrios had been added, and found that under laboratory conditions, temperature 45° to 64° F., at least 99.9 per cent. of the vibrios perished within one week. A period of three weeks' storage was sufficient in all the experiments to arrive at a result when cholera vibrios could no longer be isolated from 100 c.c. of the water. The initial infections were very heavy and ranged from 70,000 to 13 millions per c.c. of water, a concentration far greater than is ever likely to occur in water under natural conditions. On the other hand, it is probable that extinction of the vibrios would be less rapid in the case, for example, of accidental contamination of a pure or almost sterile water, especially in cold weather.

Experiments by Greig (1914) demonstrated amongst other things that, as in the case of typhoid bacteria, uncultivated cholera vibrios die much sooner than cultivated vibrios, and also that temperature exerted a marked influence on the rate of death.

It has been observed by Hankin and others that certain river waters, such as those of the Ganges and Jumna in India, are peculiarly

destructive to cholera vibrios, death occurring in a few hours. The presence in these waters of a cholera bacteriophage was suggested by d'Herelle to be the explanation of this action.

Survival of the cholera vibrios outside the human body in sewage, water, etc., plays only a secondary part in perpetuating cholera, for the life of the vibrios under these conditions is short. The main problem in the prevention of the disease centres on the case and the carrier, and an important fact in this regard is that cholera vibrios may be excreted in the faeces days before any symptoms arise. Houston (1918) expressed the opinion that most of the water-borne epidemics of infectious disease are due to accidental infection of water supplies by carriers.

Characters of *V. Cholerae*

The cholera vibrio is a short, curved, comma-shaped rod, 1 to 4 μ by 0.2 to 0.4 μ in size, actively motile (a single terminal flagellum), non-sporing, and Gram-negative. The characteristic curvature is not always apparent.

Growth is readily obtained under aerobic conditions at 37° C. by the use of ordinary laboratory media, but an acid reaction is inhibitory, and media of an initial pH of 8.0 to 9.0 are found to be the most suitable. Gelatin is liquefied (funnel-shaped liquefaction).

In broth and peptone water, after six hours' incubation the growth forms a surface pellicle, followed by a general turbidity and formation of a deposit. No pigment is produced. On neutral-red bile-salt lactose agar, clear and practically colourless colonies appear.

Indole is formed, and nitrates are reduced to nitrites. The methyl-red and Voges-Proskauer reactions are both negative. Acid, but no gas, is produced in glucose, sucrose, maltose, mannitol and dextrin. Growth soon ceases, the organisms being killed by the acidity produced. No change occurs in dulcitol, adonitol, xylose and arabinose. Acidity is not produced in lactose within forty-eight hours, but occasionally occurs as a late change (ten days). Litmus is not a good indicator in media, for it is often bleached.

The Cholera-red Reaction. A few drops of pure concentrated sulphuric acid are added to a peptone-water culture and a pink colour immediately appears. The test depends on the production by the organisms of nitrites and indole which interact with the added acid to form a nitroso-indole. The reaction is not specific, but is given also by some non-pathogenic vibrios and other organisms.

Houston (1915) has noted that the reaction is given by cholera vibrios after twenty-four and forty-eight hours' incubation, whereas some of the non-cholera vibrios which give the reaction when first tested fail when tested again after forty-eight hours' incubation. Also, subcultures may then fail even when tested after twenty-four hours. Whilst *V. cholerae* practically always gives the reaction, most of the saprophytic vibrios fail to do so. Of just over 6,000 non-lactose-

fermenting colonies of organisms other than cholera vibrios isolated from samples of water, 3 per cent. gave a positive cholera-red reaction.

Special or Selected Media. *V. cholerae* tolerates a much more alkaline reaction than most other organisms, and this fact is of value in the preparation of laboratory culture media.

Being strongly aerobic the cholera vibrios grow particularly well at the surface of peptone water. The medium consists of 1 per cent. peptone and 0.5 per cent. sodium chloride in water, and is adjusted to pH 8.0 to 9.0.

Of solid media for the direct isolation of *V. cholerae*, Dieudonné's alkaline blood agar is probably the best and most selective, and is particularly useful for the direct isolation of the organisms from choleraic stools, when almost pure cultures may be obtained.

Isolation of Cholera Vibrios from Water

Peptone water is the medium of choice for the primary cultures, and the advantage of a faintly alkaline reaction has already been mentioned.

The sample under examination should be large in volume, should be packed in ice during transit to the laboratory and examination should follow with the least possible delay.

To 900 c.c. of the sample are added 100 c.c. of a sterile concentrated peptone solution containing 10 per cent. of peptone and 5 per cent. of sodium chloride. The resultant mixture therefore constitutes a 1 per cent. peptone water with 0.5 per cent. sodium chloride, and is conveniently distributed for incubation into several sterile flasks. After six, twelve, twenty-four and forty-eight hours' incubation at 37° C., subcultures from the surface of the fluids in the flasks should be made on agar (3 per cent. pH 8 — 9) or Dieudonné plates, which are incubated at 37° C. for twenty-four hours.

From isolated colonies pure cultures can be made, and then submitted to morphological, cultural and biochemical tests. The procedure found most satisfactory by Houston in his investigations concerning the isolation of cholera vibrios from impure river waters was as follows :—

Likely colonies developing on the agar plates are each inoculated into two tubes of suitable peptone water, and incubated. One is then tested for the cholera-red reaction. If the reaction is positive the other tube is used for further investigations as follows :—

- | | |
|---|---|
| 1. Neutral-red bile-salt lactose agar . . . | Colourless colonies. |
| 2. " " " sucrose agar . . . | Red colonies. |
| 3. Liquid sugar media (1) glucose . . . | Acid, no gas. |
| (2) sucrose . . . | Acid, no gas. |
| (3) dextrin . . . | Acid, no gas. |
| (4) salicin . . . | No change. |
| 4. Peptone water . . . | For cholera-red reaction in forty-eight hours as well as twenty-four hours. |
| 5. Gelatin slope . . . | Funnel-shaped liquefaction. |
| 6. Mixed sugar . . . | This is more delicate than liquid sugar media for showing gas formation. |
| Gelatin medium . . . | |

Any cultures of actively motile vibrios giving the correct series of reactions must then be submitted to the following confirmatory tests.

Confirmatory Tests

1. Serological

(1) Agglutination reaction with cholera antiserum.

A positive reaction is not absolute proof, and the fact that repeated subculture may change a negative to a positive reaction must not be forgotten; inagglutinability does not prove a vibrio is not *V. cholerae*, and there is reason to believe that the passage of cholera vibrios through water may bring about this result.

(2) Agglutinin-absorption and complement-fixation tests.

2. Animal Tests

(1) Pfeiffer's reaction, or bacteriolytic test.

(2) Pathogenicity to laboratory animals.

The identification of a vibrio as *V. cholerae*, especially when isolated from water, is a matter requiring most careful investigation.

Only presumptive evidence can be adduced on morphology, cultural characters and biochemical reactions.

Vibrios in Water

A variety of vibrios, many bearing close resemblance to *V. cholerae*, are found in non-cholera-infected water. The majority of those isolated by Houston from the waters of the Thames, Lee and New River, were readily excluded by the tests enumerated above; thus 97 per cent. failed to give the cholera-red reaction, and, of the remainder, 86 per cent. were excluded as gas-producers in sugar media.

The relationship of the non-pathogenic vibrios to *V. cholerae* is undecided, and it is uncertain whether the one may become the other under suitable circumstances of environment. Mackie (1929) stated: "While some vibrios isolated from water are purely saprophytic growing only at room temperatures, many such organisms may only be temporarily water organisms, and may be of intestinal origin. It might be supposed that there exists a large group of closely related vibrios varying in parasitic properties and in potential pathogenicity; others may possess a somewhat lower aggressiveness and pathogenicity, *e.g.*, the para-cholera vibrios; some species are purely saprophytic, while others again may occupy an intermediate position between truly parasitic forms and such saprophytes, and it is possible that these organisms may establish themselves in the intestinal tract with or without pathogenic effects."

According to the same author the essential characters by which collectively the *V. cholerae* species may be readily distinguished from other members of the genus are:—

1. Motility—single terminal flagellum.
2. Aerobic growth.
3. Absence of phosphorescence.

TABLE IV. SHOWING SOME OF THE VIBRIOS THAT MAY BE FOUND IN WATER (Compiled from "System of Bacteriology," Med. Res. Council, Vol. 4).

Group.	Names.	Material from which Isolated.	Distinction from <i>V. cholerae</i> .
1. Vibrios of high virulence to guinea-pigs and pigeons.	<i>V. metchnikovi</i> .	Enteritis in fowls, "cholera" in man. Sewage. River water.	Serologically distinct, and high virulence to pigeons.
2. <i>Vibrio gindha</i> type . .	<i>V. gindha</i> .	Water.	Serologically distinct, non-pathogenic to laboratory animals.
3. <i>Vibrio proteus</i> type . .	Findler and Prior's vibrio.	Dejecta of man (choleraic diarrhoea), water.	Negative indole and cholera-red reactions, serologically distinct.
4. Phosphorescent vibrios .	<i>V. phosphorescens</i> . <i>V. albensis</i> .	River waters. Stools of man (chol. diarrhoea).	Exhibits phosphorescence in broth and gelatin cultures at 22° C. Serologically distinct.
5. Chromogenic vibrios .	<i>V. drennani</i> . <i>V. aureus</i> . <i>V. aquatilis</i> fluorescens.	Man. Canal mud. Water.	Dark brown growth on agar and in peptone water. No indole. Golden-yellow pigment produced. Green fluorescent pigment produced.
6. Non-proteolytic vibrios .	<i>V. bonhoffii</i> .	Water.	Gelatin not liquefied.
7. Vibrios growing only at low temperature.	<i>V. marinus</i> . <i>V. portuensis</i> .	Sea water. Water.	Failure to grow at 37° C., white growth on agar. Multiple flagella, no growth above 30° C., no liquefaction of gelatin. Non-virulent to guinea-pigs.
8. Vibrios of fish and molluscs	<i>V. anguillarum</i> . <i>V. piscium</i> . <i>V. carchii</i> .	Eels. Carp. Mussel.	Gas production on sugar media, negative cholera-red reaction. Failure to grow at 37° C. One or two flagella, negative cholera-red reaction.

4. Absence of pigment in peptone-water cultures.
5. The cholera-red reaction.
6. Funnel-shaped liquefaction of gelatin.
7. Pathogenicity to laboratory animals by intraperitoneal and intravenous injection, low virulence for pigeons by intramuscular injection.
8. Specific serological reactions with homologous antisera.

It will be noted that fermentation reactions are excluded from the above, but whilst they fail to distinguish *V. cholerae* from some closely similar vibrios, Houston's results show how useful the sugars are in distinguishing water vibrios from *V. cholerae*.

Apart from the true cholera vibrio, pathogenic vibrios, such as *V. metchnikovi*, which are only distinguishable by serological reactions, may rarely be found in water.

The greater number of vibrios are differentiated by morphological, cultural and biochemical characters. Thus, some are multiflagellate, many fail to give the cholera-red reaction, some produce phosphorescence or pigment in culture media, or gas in sugar media, whilst others fail to liquefy gelatin or cannot grow at blood-heat.

A number of these vibrios are classified in Table IV.

Resistance of Cholera Vibrio. The cholera vibrio has little resistance to drying, heat, or disinfectants. It is destroyed by heating to 55° C. in under half an hour and cholera-infected water is rendered safe by boiling. Storage of water for three to four weeks results in the almost complete destruction of *V. cholerae*.

Chlorination, properly carried out, is an effective safeguard.

References

- BEGGIE and GIBSON. 1930. *Brit. Med. J.*, II., 55.
 DUDGEON. 1919. *Med. Res. Council, Spec. Rep. Series*, No. 40.
 FLETCHER. 1917-18. *Roy. Army Med. Corps J.*, 29, 545; 30, 679.
 GRAY. 1929. *Brit. Med. J.*, I., 142.
 GREIG. 1914. *Ind. J. Med. Res.*, 2, 1.
 HARVEY. 1915. *Roy. Army Med. Corps J.*, 24, 491.
 HOUSTON. 1908-15. 1st-11th Research Reports to the Met. Wat. Bd.
 1913. "Studies in Water Supply."
 1928-31. 23rd-26th Annual Reports to the Met. Wat. Bd.
 JONES. 1936. *J. Path. Bact.*, 42, 455.
 JORDAN, RUSSELL and ZEIT. 1904. *J. Infect. Dis.*, 1, 641.
 KAUFFMANN. 1935-36. *Z. Hyg.*, 117, 26.
 LEIFSON. 1935. *J. Path. Bact.*, 40, 581.
 MACKIE. 1929. "System of Bacteriology," Vol. 4, Med. Res. Council.
 MINISTRY OF HEALTH. 1938. *Reports Publ. Hlth. Med. Sub.*, No. 82.
 MULLER. 1923. *C.R. Soc. Biol.*, 89, 434.
 RUCHHOFF. 1934. *Sewage Works J.*, 6, 1054.
 SCOTT. 1931. Quoted from *An. Rep. of Chief Med. Off., Min. of Health*.
 SZPER. 1935. *C. R. Soc. Biol.*, 118, 1675.
 TABET. 1938. *J. Path. Bact.*, 46, 181.
 TYAGARAJA. 1940. *J. Hyg.*, 40, 414.
 WHITE. 1929. "System of Bacteriology," Vol. 4, Med. Res. Council.
 WILSON. 1928. *Brit. Med. J.*, I., 1061; 1938. *J. Hyg.*, 38, 507.
 WILSON and BLAIR. 1931. *J. Hyg.*, 31, 138.

CHAPTER XXXIV

THE BACTERIOLOGICAL EXAMINATION OF GROSSLY POLLUTED WATER

THE water bacteriologist is frequently required to examine such grossly polluted liquids as sewage, sewage effluents, trade wastes, discharges from farmyards, land drains, etc.

In the consideration of any river as a probable source of supply for drinking purposes, the character, both chemical and bacteriological, of all discharges into it above the proposed point of intake must be ascertained, and their effect on the river water determined. There are few rivers in this country which do not receive pollution in some part of their course, and since rivers are rapidly increasing in importance as sources of water supply, it is of paramount importance that pollution should be restricted to a minimum.

Sewage is a very complex liquor, both chemically and bacteriologically, but the component of the greatest importance as regards water supplies is that derived from excreta, particularly of human origin.

Human excrement contains about one-quarter to one-third its weight of bacteria, and although most of these bacteria are dead, large numbers, which may exceed 1,000 millions per gramme, are alive and capable of reproduction.

The bacteria in fresh sewage are primarily those of fæces, with additions from the other matters that go to make up sewage. They include :—

1. Gram-negative coliform bacteria of which over 90 per cent. are *Bact. coli*.
2. Gram-positive cocci, *e.g.*, staphylococci, streptococci, etc.
3. *Sarcinæ* and other micrococci.
4. Anaerobic spore-formers, *e.g.*, *Cl. welchii*.
5. Aerobic sporing bacilli, *e.g.*, *B. subtilis*, *B. mycoides*, etc.
6. Aciduric bacteria.
7. Thermophilic bacteria.
8. Proteus bacteria and other liquefying organisms, such as *Bact. liquefaciens* and *Bact. effluviæ* (Wilson, 1928).
9. Yeasts.
10. Spirilla.
11. *Bact. pyocyaneum*.
12. *Bact. morgani*.
13. Pathogens, such as *Bact. typhosum*, *Bact. paratyphosum*, *Bact. dysenteriæ*, etc.

The bacterial population of sewage undergoes frequent, rapid and marked changes. The medium provides a rich food supply for many bacteria, but other influences, such as temperature, reaction, etc., may be unfavourable, and hence, while some bacteria multiply in sewage, others die out. In old stored sewage *Bact. coli* may decrease relatively to enterococci, *Proteus* and putrefactive bacteria, owing to the multiplication of the latter organisms. Typhoid and paratyphoid bacteria are frequently present, often in quite unexpected number, in sewage and sewage effluents, and, although they do not multiply but, as a rule, perish fairly quickly, they may persist for days or, under exceptional conditions, even for weeks. Their presence is due not only to cases of the diseases, but also to the existence of carriers amongst the population.

Other pathogenic bacteria, such as the *Salmonella* (food-poisoning) bacteria, may be derived from the excreta of man and animals.

Sewage should always be regarded as containing the bacteria of disease, and, since the ordinary methods of sewage purification effect no significant bacterial removal or destruction, effluents, even when of a high standard as judged by chemical analysis, should be regarded as little less dangerous than sewage. All sewage effluents, whatever the system of purification, are, unless subjected to some sterilisation process, exceedingly impure bacteriologically, and a source of danger when discharged into rivers. This danger may arise from the use of the water for drinking purposes, for dairy use, as in the cooling of milk and the washing of utensils, for bathing, or for the cultivation of water-cress, oysters and other shellfish.

The number of bacteria found in sewage and sewage effluents is, as previously stated, subject to great variation, depending, amongst other things, on the locality, the "strength" of the sewage, the method of treatment, the age of the sample when examined, and the technique of sampling and examination. Night sewage is usually more dilute than day, and changes proceed more rapidly in warm weather than in cold. The estimations of various workers show therefore the widest differences, but Houston gave the following as average figures :—

	Bacteria Growing on Gelatin in 3 days at 20° C. per c.c.	Bacteria Growing on Agar in 1 day at 37° C. per c.c.	Bact. coli. per c.c.
Sewage .	10 millions to 100 millions.	1 million to 10 millions.	100,000
Effluents	1,000 to 1,000,000	1,000 to 100,000	10,000

In fresh sewage, faecal streptococci and clostridial spores are present to less extent than *Bact. coli*, the former in about 1/100th and the latter less than 1/1000th the number.

Proteus may be comparatively few in number in fresh sewage, but may number several hundred thousands per c.c. in samples collected at the sewage disposal works.

The general tendency of pathogenic bacteria, such as *Bact. typhosum*, is to decrease in number, but the rate of death is variable, and recent experience indicates that it may be less rapid than was generally supposed. Typhoid bacteria have been cultivated from human faeces which had been stored for fifty-two days, and from sewage sludge after thirty-five days' storage. Paratyphoid bacteria are no less resistant than typhoid bacteria.

Methods of Examination of Sewage and Sewage Effluents

Sampling is of great importance, and the proper relation of solids to liquid should be maintained as far as possible in order to get representative samples. A number of samples collected at various hours of the day and night should be examined, owing to the great variations that always occur in the "strength" of sewage throughout the twenty-four hours. Also, it must be remembered that domestic sewage varies not only hourly, but also daily, and is often stronger on some days of the week than on others.

The discharge of certain industrial wastes into the sewers may, owing to the presence of disinfectants, give rise to abnormally low bacterial counts in the sewage, whilst, on the other hand, other wastes may add bacteria or promote their rapid multiplication. Information should therefore be obtained concerning the nature of the sewage, whether purely domestic or containing much trade waste. The history of a sample of sewage is important to the bacteriologist, as in the case of a sample of water.

The sample should be conveyed to the laboratory packed in ice, and the examination commenced as quickly as possible. This point is more important than in the case of waters, for changes occur more rapidly.

The sample, whether of raw sewage or sewage effluent, is vigorously shaken in a bottle of ample surplus capacity in order to get as uniform a mixture as possible.

Dilutions with sterile water of 1 in 10, 1 in 100, 1 in 1,000, 1 in 10,000 and so on are then made, the series being prepared with 10 c.c. quantities from each, in glass-stoppered bottles of 150 to 200 c.c. capacity, to permit of good mixing by shaking.

The determinations usually performed are :—

1. Enumeration of the bacteria capable of growing on agar in one day and two days at 37° C. per c.c.
2. Enumeration of the bacteria capable of growing on agar or gelatin in three days at 20° C. per c.c.
3. Enumeration of the coliform colonies growing at 37° C. in one day per c.c. on a selective medium, such as neutral-red bile-salt lactose agar.
4. Estimation of the approximate number of *Bact. coli* by the use of a liquid medium, *e.g.*, MacConkey's broth.
5. Estimation of the approximate number of *Cl. welchii* and allied spores.
6. Estimation of the approximate number of faecal streptococci.

The bacterial enumerations are carried out as in the case of water, except that much smaller quantities of the sample are taken, in order to prevent overcrowding of the plates. Quantities which generally prove suitable are :—

	Sewages and Tank Liquors.	Final Effluents.
Agar at 37° C. . c.c.	1/1,000th, 1/10,000th	1/100th 1/1,000th
Agar or gelatin at 20° C. c.c.	1/10,000th, 1/100,000th	1/1,000th, 1/10,000th
Neutral-red bile-salt lactose agar . c.c.	1/1,000th 1/10,000th	1/100th, 1/1,000th

The counts on agar at blood heat and the coliform count are of greater value than the counts at 20° C., and the latter can often be omitted.

The presence and approximate number of *Bact. coli* are established as in the case of water. Primary cultures are obtained in bile-salt lactose litmus broth incubated at 37° C. for twenty-four to forty-eight hours. Inoculations are made from the series of dilutions prepared from the sample, and the extent of this series must be decided by the nature of the sample, the object being to obtain both positive and negative results. Usually with any liquor except strong sewage a quantity of one-millionth of a c.c. gives a negative result, but one-tenth of this quantity may sometimes be required.

The production of acid and gas is a positive result, and in our experience this result in twenty-four hours' or less incubation is almost invariably due to *Bact. coli*. Positive results occurring only on the second day of incubation are less likely to be due to *Bact. coli*, and should be confirmed.

Confirmation is obtained, as in the case of water, by plating on solid media, such as neutral-red bile-salt lactose agar, picking off appropriate colonies and subjecting the pure cultures to morphological study, cultivation in lactose medium for acid and gas formation and to the various differential tests (see p. 474).

The examination for faecal streptococci is conducted in the same way as with waters, but usually it adds little information, and can be neglected.

The test for Clostridial spores consists in the heating of the dilutions of the sample to 80° C. for fifteen minutes, followed by inoculations into sterile milk for the stormy fermentation reaction. Incubation proceeds for four days at 37° C. Alternatively the sulphite-iron-agar medium of Wilson and Blair may be used where enumeration of the Clostridial colonies is desired.

The most generally useful bacteriological determinations on liquids of this kind are therefore :—

1. Bacterial count on agar, incubated at 37° C.
2. "Coliform" count on neutral-red bile-salt lactose agar or other selective medium, incubated at 37° C.

TABLE I

RESULTS OF THE CHEMICAL AND BACTERIOLOGICAL EXAMINATION OF
FIFTY CONSECUTIVE SAMPLES OF SEWAGE EFFLUENTS
Chemical Results in Parts per 100,000

Suspended Matter.	Nitric Nitrogen.	Free Ammonia.	Albuminoid Ammonia.	Oxygen Absorbed from Acid Permanganate. 3 Hours at 37° C.	Dissolved Oxygen Absorbed (B.O.D.) 5 Days.	No. of Bacteria on Gelatin per c.c. 3 Days at 20° C.	No. of Bacteria on Agar per c.c. 1 Day at 37° C.	No. of Coll.-like Colonies on Neutral-red Bile-Salt Agar per c.c. 1 Day at 37° C.	Smallest Quantity of Sample containing * Bact. coli. c.c.
11.5	0.00	5.81	1.06	15.40	—	8,200,000	115,000	—	0.00001
9.0	0.00	13.75	1.00	11.8	36.0	—	—	70,000	0.00001
12.0	0.00	2.85	1.010	6.75	24.5	5,000,000	520,000	200,000	0.00001
6.5	0.00	1.15	0.480	5.56	26.2	1,500,000	27,000	—	0.0001
20.0	0.00	1.10	1.200	4.74	26.1	6,800,000	130,000	28,000	0.001
12.0	0.00	4.66	0.510	4.74	—	2,500,000	220,000	—	0.00001
4.0	0.00	5.20	0.40	3.80	13.6	10,000,000	380,000	34,000	0.0001
3.2	0.00	2.55	0.425	3.25	—	19,000,000	1,500,000	—	0.00001
—	0.00	4.20	0.800	3.14	—	3,700,000	608,000	—	0.00001
5.0	0.00	4.85	0.48	3.14	7.6	14,000,000	630,000	120,000	0.00001
2.4	0.00	3.20	1.22	3.13	8.4	16,000,000	156,000	16,000	0.0001
5.0	0.00	1.275	0.55	3.10	24.5	31,000,000	1,600,000	160,000	0.00001
3.0	0.00	4.200	0.370	2.96	9.8	1,800,000	300,000	60,000	0.0001
2.0	0.00	3.25	0.280	2.68	8.0	5,600,000	400,000	26,000	0.0001
4.5	0.00	1.35	0.210	2.54	12.5	700,000	47,000	—	0.00001
1.5	0.44	1.56	0.286	2.24	—	2,100,000	180,000	27,000	0.0001
5.4	0.00	3.50	0.210	2.24	—	6,700,000	552,000	—	0.00001
2.0	1.20	0.650	0.180	2.24	—	450,000	73,000	—	0.0001
3.0	0.40	3.75	0.220	1.92	2.0	1,100,000	62,000	14,400	0.0001
1.3	0.52	1.65	0.10	1.33	2.4	2,300,000	420,000	10,000	0.0001
1.5	2.60	2.45	0.150	1.24	2.5	3,000,000	140,000	—	0.0001
2.8	1.75	0.54	0.150	1.24	1.65	2,100,000	21,000	10,800	0.0001
—	3.50	1.22	0.088	1.22	—	1,800,000	460,000	—	0.00001
1.0	0.20	1.05	0.105	1.21	—	2,000,000	130,000	—	0.0001
1.0	2.10	0.225	0.100	1.2	—	700,000	4,500	—	0.001
2.2	1.50	0.33	0.100	1.17	1.8	110,000	8,000	110	0.01
2.0	1.10	0.980	0.260	1.09	3.5	1,200,000	41,000	8,000	0.0001
1.8	0.00	2.00	0.196	0.95	2.8	2,100,000	200,000	4,200	0.0001
1.5	0.10	1.80	0.184	0.92	2.4	2,500,000	230,000	7,000	0.00001
1.0	0.00	0.450	0.080	0.90	1.95	4,000,000	900,000	100,000	0.00001
1.3	1.9	0.240	0.110	0.86	1.5	—	12,000	7,200	0.0001
1.0	1.85	0.080	0.110	0.82	—	2,300,000	3,800	1,600	0.001
1.0	2.1	0.31	0.100	0.76	1.26	—	7,000	3,800	0.001
1.0	3.20	0.75	0.09	0.74	1.4	1,400,000	32,000	16,800	0.0001
3.5	0.52	0.27	0.13	0.70	2.4	1,100,000	50,000	7,000	0.001
1.0	4.25	0.055	0.080	0.66	1.0	2,800,000	15,200	540	0.001
1.0	0.84	0.350	0.110	0.65	—	260,000	7,200	1,500	0.001
1.0	2.1	0.024	0.070	0.64	—	40,000	3,100	1,700	0.001
2.0	0.64	0.48	0.080	0.63	—	520,000	23,000	—	0.001
1.0	0.20	0.62	0.078	0.58	—	1,500,000	600,000	—	0.0001
1.0	0.44	2.00	0.076	0.58	0.6	19,800	9,200	4,200	0.0001
1.0	1.2	0.018	0.072	0.57	0.9	410,000	16,000	900	0.001
1.0	1.40	1.200	0.075	0.54	0.40	48,000	16,000	480	0.001
1.0	1.65	0.040	0.065	0.53	0.75	—	8,600	2,300	0.0001
1.0	0.28	2.14	0.060	0.53	1.2	210,000	12,000	1,220	0.0001
1.0	2.0	0.125	0.065	0.49	0.75	—	6,500	1,600	0.001
1.0	0.40	0.210	0.040	0.46	0.7	610,000	6,000	400	0.01
1.0	0.28	0.40	0.050	0.25	—	170,000	52,000	—	0.0001
1.0	0.18	0.01	0.060	0.22	—	2,300,000	570,000	—	0.00001
1.0	0.32	0.145	0.030	0.17	0.3	720,000	26,000	410	0.01

Suspended matter less than one part per 100,000 shown as 1.0.

3. Production of acid and gas in lactose bile-salt litmus broth, followed by confirmatory tests for *Bact. coli* as required.

A minority of samples of sewage and sewage effluents are examined bacteriologically, but, for reasons already stated, it is probable that this method of examination will be more frequently employed in the future.

The results obtained in our laboratories in the examination of fifty consecutive samples of sewage effluents produced by various methods of treatment, and all being discharged into inland rivers, are shown in Table I, and the chemical analyses are given alongside so that the character of the effluents can be assessed. The samples are arranged in descending order of impurity as judged by the oxygen absorbed from acid permanganate.

The following points will be noted :—

1. The general bacterial impurity.
2. The great variation in the results, which are not always in accordance with the degree of purification as shown by chemical analysis.
3. The large number of *Bact. coli* usually present.
4. The wide variation in the ratio of the count at 20° C. to the count at 37° C.
5. The general agreement in the *Bact. coli* findings as regards the count on neutral-red bile-salt lactose agar, and acid and gas in lactose bile-salt litmus broth.

The samples cannot be compared with one another, since they represent effluents derived from different sewages, some strong, some very dilute, and treated by different methods, some (the first few in the list) by settlement in tanks only, others by tanks followed by land treatment or sprinkler percolating beds.

Also the samples were as delivered to the laboratory, and hence the period of time between collection and examination will be variable.

Although always impure from the bacteriological standpoint, effluents that have been efficiently purified as judged by chemical analyses, generally contain fewer coliform and other bacteria than effluents produced by plants of less efficiency. In broad terms, an effluent which conforms to the Royal Commission Standards (see Chapter XIX) contains from one-fifth to one-twentieth the number of bacteria originally present in the sewage. The residuum is therefore still numerically appreciable and includes most of the species that were originally present in the sewage. Pathogenic bacteria, such as the enteric organisms, may escape destruction or removal in the purification processes and appear in the effluent. Since the introduction of improved media such as the bismuth sulphite medium of Wilson and Blair (1927, 1938), typhoid and paratyphoid bacteria have frequently been isolated from sewage, effluents and river water.

Examination of Sewage and Effluents for Enteric Bacteria

The technique is in many respects similar to that described for water (see p. 533). It is not, of course, necessary to inoculate such large volumes, and concentration of the sample may be unnecessary, for enteric organisms may be found in 1 c.c.

Direct plating on MacConkey agar is seldom of use on account of the very large numbers of coliform and other sewage bacteria usually present. The bismuth sulphite medium gives the best results and is, in our experience, superior to tetrathionate broth, for the latter is very apt to permit overgrowth of *Bact. morgani* and other non-lactose-fermenters.

Bismuth sulphite agar may thus be used as the sole primary medium, and the sample examined by incorporating varying quantities in each of several plates. A useful series for raw sewage is provided by embodying 1 c.c. of the sample in each of ten "pour-plates." Smaller quantities, *e.g.*, 0.1 c.c. and 0.01 c.c., may be dealt with similarly. In the case of effluents, etc., it is usually necessary to examine from 10 c.c. to 100 c.c., and this is facilitated by centrifugalisation (with or without the aid of a coagulant). Thus, to examine 50 c.c. of a sample, fill four centrifuge tubes with 12.5 c.c. of the well-shaken liquor, and, immediately after centrifuging, pour off the supernatant fluid, leaving about 1 c.c. of liquid in each tube. The deposit is in each case thoroughly mixed with the residual liquid and the contents of each tube are incorporated in a "pour-plate." The plates are incubated at 37° C. for twenty-four and forty-eight hours, when selected colonies are picked off and subcultured in the usual manner.

The difficulties regarding black colonies are accentuated in the case of sewage and sewage effluents, for sulphite-reducing saprophytes are seldom absent. *Bact. effluviei*, first described by Wilson (1928), constitutes the main problem, being especially numerous in the late summer months. It is a Gram-negative, actively motile, non-sporing bacterium which produces on agar a growth similar to that of *Bact. coli*, but liquefies gelatin. Indole is readily formed and glucose, sucrose, maltose and mannitol are fermented with the production of acid and gas, but there is no action on lactose and dulcitol. In the bismuth medium this organism produces colonies which are very similar to those of the enteric bacteria and which can be distinguished only by further tests.

It is important, therefore, to realise that the black colonies appearing on the bismuth sulphite plate may, in the case of sewage (and water), be largely caused by saprophytes. As many of these sulphite-reducing organisms are (like *Bact. effluviei*) active indole-producers, it is of advantage to apply this test before proceeding further. Only the indole-negative organisms need then be considered, and those giving the correct fermentative reactions are confirmed or excluded by agglutination tests.

The Menace to Water Supplies of Sewage and Sewage Effluents

In view of the certain bacterial impurity and the probable presence of pathogenic organisms even in the best sewage effluents, the question of disinfection often becomes one of considerable importance. The method of disinfection that so far has proved the most practicable and efficient is chlorination. This method of treatment has been employed in certain cases for many years, but more often for deodorising purposes than for sterilisation. Certain effluents, however, owing to the proximity of their outfalls to waterworks intakes, or for other reasons, have been successfully chlorinated for many years.

The dose of chlorine required to effect good bacterial purification naturally varies greatly according to the quality of the effluent, but with filter effluents which conform to the Royal Commission standards, a dose of approximately 5 parts per million generally suffices. With such a dose the bacterial counts can be reduced to a few hundreds per c.c., and *Bact. coli* destroyed so that the majority of samples give a negative result in at least 10 c.c. We have records of many samples of effluents treated by chlorination which show less than 100 bacteria per c.c., growing on agar at 37° C., and *Bact. coli* absent from 50 c.c.

Chlorination is capable of practical and economic application, and its installation at some sewage works has proved of great value.

The chlorination of effluents has other advantages, and we have advised its use at works where much trouble arose owing to profuse growths of fungus in the effluent pipes which were of considerable length. A dose of 1 part per million of chlorine proved entirely successful in preventing such growths.

The prevention of sepsis and odours is another function of chlorination, but the dose required for the treatment of sewage and tank liquors is large, ranging usually from 15 to 20 parts per million. Septic sewage containing reducing substances, such as sulphides, requires even larger doses.

Owing to the presence of free ammonia, the addition of chlorine to sewage and sewage effluents results in the formation of chloramines. This fact, first noted by Rideal, is of importance in that the destruction of bacteria may be delayed, but it is of advantage inasmuch as the disinfecting agent is more persistent and the ultimate bactericidal efficiency is greater. An adequate dose and contact time are therefore required before the discharge of a chlorinated effluent, and suitable tankage is necessary.

The chlorination of an effluent is usually a final process, and care must be exercised to avoid excess of free chlorine entering a stream where fishing is of value.

Owing to the wide variations possible in the quality of an effluent, chlorination must be carefully controlled as regards dosage to ensure successful bacteriological results on the one hand and to avoid excess of chlorine on the other.

Whilst enteric fever is to be most feared in this country from the

pollution of water by sewage and sewage effluents, dysentery and cholera may assume an equal or greater importance in some countries, particularly in the East. The remarks concerning the former apply equally, therefore, as regards the latter. The *Salmonella* (food-poisoning) bacteria, other than *Bact. paratyphosum*, may also be present in sewage. We are not, however, aware of any outbreaks of "food-poisoning" due to sewage pollution of water, but the possibility nevertheless exists.

The fate of other pathogenic organisms, such as anthrax bacilli, tubercle bacilli, etc., in sewage and their passage through a sewage-disposal works is uncertain, but in these cases there is no evidence to associate water supplies with spread of the diseases. The occurrence of diphtheria has been ascribed to sewage and water supplies, and samples of water are occasionally sent to us for examination for *C. diphtheriæ*. There is no evidence, however, to show that sewage-polluted water plays any direct part in the epidemiology of diphtheria.

The addition of streptococci and other pyogenic bacteria by sewage to water may be responsible for the causation of diseases, such as otitis media and sinus infections, in bathers. For this and other reasons, purification of sewage-polluted river waters used for the filling of outdoor swimming pools is necessary. (See Chapter XLVIII.)

Besides the recognised organisms of disease, sewage effluents may contain and yield to water unnamed bacteria capable of causing illness, such as gastro-enteritis, among the consumers. Several outbreaks of this kind, in which the causal organism was not identified, have come to our notice.

Leptospiræ may be added to water by sewage and give rise to disease (Weil's disease) in man. Viruses may also be present, and recent investigations have, for example, demonstrated the presence in sewage of the virus causing poliomyelitis (infantile paralysis).

Sewage and sewage effluents constitute, therefore, a very considerable menace which has often been underestimated as regards water supplies, bathing pools, and other purposes to which water is applied.

In view of the increasing importance in this country of rivers as sources of water supply, we are of opinion that additional processes in the purification of sewage are often required. Of these, sand filtration and chlorination appear the most desirable, and they should be considered as adjuncts to the tanks, percolating filters, etc., customarily in use, and, in certain instances, applied as final processes to the effluents obtained therefrom.

References

- WILSON and BLAIR. 1927. *J. Hyg. Camb.*, 26, 374.
WILSON. 1928. *Brit. Med. J.*, *i.*, 1061.
WILSON. 1938. *J. Hyg. Camb.*, 38, 507.

CHAPTER XXXV

THE RESULTS OBTAINED IN THE EXAMINATION OF SAMPLES OF WATER

THE factors that influence the number and species of bacteria found in water, and the methods employed for their detection and enumeration, have already been described. In the present pages, the results obtained in the examination, by these methods, of waters derived from sources of different character will be shown and discussed. The results are extracted from our records, and they illustrate the quality of English water supplies.

It is not possible to indicate the quality of waters solely by bacteriological data and therefore parts of the chemical analyses will also be included.

Waters can conveniently be classified according to the proximity of their sources to the ground surface.

Thus, waters of rivers, lakes, impounding reservoirs, etc., are referred to as surface waters, waters from some shallow wells and springs as subsoil waters, and waters derived from boreholes piercing an impermeable stratum as deep or underground waters.

Great variations, both quantitative and qualitative, are found to occur in the bacterial content of different samples of water of any one class, and results, even of a large number of samples, can be considered only as broadly representative.

(1) Surface Water

(1) **Rain-water.** The direct collection of rain-water is an unreliable method of providing a water supply, but owing to the absence of a public supply, or other local sources of water, it is necessary at some isolated houses and small country communities.

The quality of rain-water varies according to the locality, and the methods of collection and storage. Rain which has fallen through the smoky and dirt-laden air of large towns is found to contain numerous bacteria, whilst in districts remote from habitations and factories, 0 to 10 per c.c. are common numbers. The number of bacteria in samples varies also according to season, and is greater at the beginning of rainfall than if collected after it has continued for some time.

The cleanliness of the surface on which rain is collected also affects the bacterial purity of the water. Roofs of buildings are the usual surfaces employed, and hence many bacteria are added from bird-droppings, accumulated dust, etc., on the roofs and in the gutters. Rain-water separators are beneficial, but are not frequently employed.

It is customary to run the water from the roofs into storage tanks, which are often situated underground. Many such rain-water storage tanks are found to contain much putrescible deposit and slime, and the water consequently becomes laden with bacteria, unsightly in appearance, and objectionable in odour. These tanks should be impervious, properly covered and so arranged that periodical cleaning can conveniently be carried out.

Rough filtration through beds of gravel, sand, coke or charcoal is often applied to the water before discharge to the storage tanks. Such "strainers" require supervision and periodical renewal of the medium, for it is often found that instead of effecting improvement they add foreign matter and bacteria to the water.

A summary of the analyses of samples of water obtained from twenty rain-water storage tanks is given in Table I, and the extent to which such water can differ from pure rain-water in organic and bacterial purity, as well as in chemical characteristics, is very great. Asbestos sheeting roofs, concrete tanks, and bird-droppings, doubtless account for most of the mineral matter in solution.

TABLE I
SUMMARY OF THE RESULTS OF ANALYSIS OF TWENTY SAMPLES OF
RAIN-WATER COLLECTED FROM ROOFS AND STORED IN TANKS

Chemical Results in Parts per 100,000

	Highest.	Lowest.	Average.
Chlorine in chlorides	10.3	0.6	4.2
Hardness : Permanent	20.0	0.0	6.0
Total	37.5	3.0	13.0
Free ammonia	0.0820	0.0040	0.0212
Albuminoid ammonia	0.0410	0.0082	0.021
Oxygen absorbed from permanganate in 3 hours at 37° C.	0.570	0.090	0.320
No. of bacteria per c.c. on gelatin in 3 days at 20° C.	Over 100,000	140	7,800
No. of bacteria per c.c. on agar in 1 day at 37° C.	Over 10,000	1	28
60 per cent. of samples containing Bact. coli in 100 c.c. or less.			
50 " " " " "	"	10 c.c.	"
25 " " " " "	"	1 c.c.	"
No " "	"	0.1 c.c.	"

The bacterial condition of these waters usually leaves much to be desired. The bacterial counts are often very high, and Bact. coli is frequently present in appreciable numbers. These bacteria are mostly derived from the excrement of birds deposited on the roofs, but the waters cannot be passed as clean, and the presence of the bacteria with much organic matter indicates the necessity for improved methods of collection, filtration or storage.

Considerable multiplication of bacteria and other low forms of life takes place in dirty storage tanks, particularly in hot weather.

The periodical addition to the tank of an appropriate amount of a disinfectant, such as bleach or hypochlorite solution, is beneficial in maintaining the cleanliness of the water.

An important consideration in rain-water supplies is the plumbosolvent properties of such water. Protection against the danger arising therefrom is obtained by prohibiting the use of lead pipes and tanks, or by introducing carbonate alkalinity into the waters.

(2) **Ponds, Lakes and Impounding Reservoirs.** These surface waters may vary from almost pure rain-water to grossly polluted waters, depending on the character of the gathering grounds, and the protection afforded in collection and storage.

In rare instances, ponds still provide the water supply to country cottages, and the quality of the water is usually poor and variable according to topographical circumstances and climatic conditions.

Samples collected after heavy rainfall may prove very turbid and unsatisfactory, whilst others collected during a period of drought, when purification by storage has occurred, may show a reasonable degree of purity. As a general rule the water of ponds is unsuitable for drinking and domestic purposes, and when no alternative source of water is available, an appropriate form of treatment should be employed.

Mountain lakes and impounding reservoirs provide the water supplies to many large communities, such as Glasgow, Manchester, Liverpool, Birmingham, Sheffield, etc., and consideration has been given to the lakes in the Welsh mountains as a source of supply to London. A summary of the analyses of samples of water from several of such lakes and impounding reservoirs is given in Table II. These waters vary in their mineral constituents according to location. The lakes and impounding reservoirs of Scotland, Wales, North England, Devon and Cornwall generally yield a soft, slightly acid water with corrosive and plumbo-solvent properties. Impounded waters in the chalk and clay areas of England are usually neutral in reaction and hard in character. Both types vary in organic and bacterial purity according to the character of the habitations and agricultural activities on the gathering grounds.

Moorland surface waters are frequently coloured yellow or brown by vegetable matter and contain a little debris in suspension, but the amount of life, such as algæ, protozoa, etc., is usually small. Filtration is usually required where these waters are used for public supplies, and chlorination is often employed as an additional bacterial safeguard. Anti-corrosion treatment is also frequently advisable.

(3) **Rivers.** Owing to the inadequacy of underground sources to meet the growing demands for water, rivers are rapidly increasing in importance as sources of supply for drinking and domestic purposes, and much attention has been given to this matter as regards both the purity and treatment of the waters.

The quality of river water is subject to the widest variation, accord-

TABLE II
SHOWING THE ANALYSES OF SAMPLES OF WATER FROM LAKES AND IMPOUNDING RESERVOIRS
Chemical Results in Parts per 100,000

No.	Source.	Colour Hazen Scale.	pH	Free CO ₂	Alka- linity CaCO ₃	Total Solids.	Total Hard- ness.	Perm- anent Hard- ness.	Free Ammo- nia.	Albu- minoid Ammo- nia.	Oxygen Absor- bed 4 hours at 27° C.	Bacterial Counts per c.c. on Agar.				Percentage of Samples containing Bact. Coli in			
												1 Day at 37° C.	2 Days at 37° C.	3 Days at 20° C.	100 c.c. or less.	10 c.c. or ess.	1 c.c. or less.	0.1 c.c. or less.	0.01 c.c. or less.
1	Lake, N. Wales . .	30	5.8	0.4	0.20	5.4	1.0	1.0	0.0006	0.0106	0.275	1	2	13	33	0	0	0	0
2	Lake, Cumberland .	12	6.3	0.3	0.25	2.8	0.9	0.9	0.0018	0.0030	0.083	18	25	290	100	100	0	0	0
3	Impounding Reservoir, Cheshire . . .	15	6.3	0.4	0.40	5.8	2.0	2.0	0.0028	0.0063	0.110	20	21	380	100	100	50	0	0
4	Lake, N. Wales . .	22	7.2	0.8	3.0	21.0	6.0	5.0	0.0050	0.0160	0.170	120	170	860	70	06	20	0	0
5	Impounding Reservoir, Cornwall . . .	20	6.8	0.4	1.5	11.0	3.2	3.2	0.0060	0.0210	0.240	220	310	920	97	32	32	3	0
6	Impounding Reservoir, Northants . . .	15	7.7	0.8	14.0	28.5	20.0	8.0	0.0052	0.0185	0.142	64	88	670	79	26	0	0	0
7	Impounding Reservoir, Warwickshire . .	35	7.6	0.9	14.0	26.5	19.0	7.0	0.0056	0.0300	0.300	160	340	1,600	87	78	52	26	9
8	Impounding Reservoir, Leicestershire . .	20	7.9	0.3	8.0	21.5	17.0	11.0	0.0044	0.0220	0.100	690	1,500	2,500	66	45	0	0	0
9	Impounding Reservoir, Essex . . .	23	8.1	0.2	13.5	29.0	20.0	8.5	0.0040	0.0380	0.241	22	—	560	62	9	0	0	0
10	Impounding Reservoir, Westmorland . .	15	6.8	0.4	—	5.7	3.5	3.5	0.0110	0.0150	0.150	8	—	2,800	100	0	0	0	0

ing to the character of the gathering ground, the land over which the river flows, the discharges of sewage, trade-wastes, etc., it receives, the season of the year and climatic conditions.

Examples of this variation are given in Table III, which shows the results obtained in the examination of a series of samples collected during a period of twelve months at a fixed point on the River Thames.

TABLE III
HIGHEST AND LOWEST FIGURES OBTAINED IN THE ANALYSES OF 134
SAMPLES OF RIVER THAMES WATER TAKEN AT A FIXED POINT

Parts per 100,000	Highest.	Lowest.
Colour—A. P. H. A.	130	12
Total solids	45.5	23.5
Chlorine in chlorides	2.4	1.3
Total hardness	35.0	17.0
Nitric nitrogen	0.40	0.05
Free ammonia	0.026	0.0004
Albuminoid ammonia	0.080	0.007
Oxygen absorbed from permanganate in 3 hours at 37° C.	0.980	0.075
No. of bacteria growing on gelatin in 3 days at 20° C.	250,000	140
No. of bacteria growing on agar in 1 day at 37° C.	13,200	17
Bact. coli: Present in	0.001 c.c.	10 c.c.
Absent in	0.0001 c.c.	1 c.c.
Cl. welchii reaction	+ 1 c.c.	— 100 c.c.

TABLE IV
SHOWING THE QUALITY OF THE RIVER DEE WATER NEAR ITS
ORIGIN AND NEAR CHESTER

Parts per 100 000 (Averages).	Near Origin.	At Chester.
Chlorine	0.8	1.7
Total hardness	1.0	6.7
Free ammonia	0.0031	0.0238
Albuminoid ammonia	0.0100	0.0200
Oxygen absorbed from permanganate in 3 hours at 37° C.	0.2420	0.3370
No. of bacteria growing on gelatin in 3 days at 20° C.	480	17,500
No. of bacteria growing on agar in 1 day at 37° C.	36	1,720
Percentage of samples containing—		
Bact. coli in 10 c.c. or less	85	100
„ „ 1 c.c. „	62	100
„ „ 0.1 c.c. „	12	100
„ „ 0.01 c.c. „	0	25

In order to ascertain the quality of a river water at any one point, such as at a proposed waterworks intake, a large number of samples

should be collected over an extended period, including all seasons of the year.

The character of the water differs not only with each individual river, but also at many points along the course of the same river.

At the head-waters of a river the quality of the water is usually good, but as the river proceeds on its course considerable deterioration often takes place. This is well shown in Table IV, although in the case of this river, sewage pollution was occurring at its origin, otherwise the difference would be still more striking.

Samples of river water collected downstream of sewage works outfalls show considerable deterioration depending on the relative qualities of the sewage effluent and river water, the dilution, and the distance from the outfall.

Two examples are given in Table V, the first being one of pollution by an unsatisfactorily purified effluent, and the second that of a good effluent readily complying with the Royal Commission standards, and both receiving approximately the same dilution of 10 to 1 by the river water.

TABLE V

SHOWING THE EFFECT OF SEWAGE EFFLUENT ON RIVER WATERS
SAMPLES COLLECTED 30 YARDS ABOVE AND BELOW EFFLUENT OUTFALLS

Parts per 100,000.	A Bad Effluent.		A Good Effluent.	
	River Above.	River Below.	River Above.	River Below.
Free ammonia	0.004	0.415	0.0036	0.185
Albuminoid ammonia	0.020	0.045	0.0032	0.0085
Oxygen absorbed from perman- ganate in 3 hours at 37° C. . .	0.23	0.49	0.18	0.30
Dissolved oxygen absorbed, 5 days	0.3	1.2	0.2	0.3
No. of bacteria growing on gelatin in 3 days at 20° C. . .	4,900	300,000	220	2,800
No. of bacteria growing on agar in 1 day at 37° C.	142	19,600	17	960
Bact. coli : Present in	1 c.c.	0.001 c.c.	10 c.c.	0.01 c.c.
Absent in	0.1 c.c.	0.0001 c.c.	1 c.c.	0.001 c.c.

The quality of a number of river waters is demonstrated in Table VI, which summarises the analyses of 1,769 samples of water collected from twenty different rivers.

Nos. 1, 2 and 3 are the three river sources supplying London, and the figures are taken from the Thirty-second Annual Report of the Director of Water Examinations to the Metropolitan Water Board.

The quality of the River Thames water in its lower reaches is shown in Nos. 4, 5 and 6, and the deterioration as the river proceeds seawards will be observed. At Staines the water is well upstream of London, whilst at Battersea it is passing through the metropolis and is within reach of tidal influence.

TABLE VI. SHOWING THE ANALYSES OF SAMPLES OF RIVER WATERS—AVERAGES—RESULTS IN PARTS PER 100,000

River.	No. of Samples.	Chlorine. Chlorides.	Per- manent Hard- ness.	Total Hard- ness.	Free Ammonia.	Albu- minoid Ammonia.	Oxygen Absorbed from Permanga- nate. 3 hours at 57° C.	Gelatin Count. 1 c.c. 1 day. 20° C.	Agar Count. 1 c.c. 1 day. 37° C.	Percentage of Samples containing Bact. Coli in			
										10 c.c. or less.	1 c.c. or less.	0-1 c.c. or less.	0-01 c.c. or less.
1. Thames, Walton . . .	246	2-01	5-5	21-9	0-0176	0-0240	0-261	—	584	99-5	92-6	63-7	17-8
2. Lee, Chingford Mill . .	246	2-80	8-2	27-8	0-0171	0-0199	0-230	—	575	100	93-0	53-2	15-4
3. New, Boves Park . . .	246	2-64	6-3	26-2	0-0133	0-0124	0-122	—	125	99-1	72-7	22-7	1-2
4. Thames, Staines . . .	100	1-7	5-0	22-0	0-0088	0-0211	0-332	9,210	1,120	100	96-0	79-0	30-0
5. Thames, Battersea . . .	50	5-6	5-5	22-0	0-0725	0-0436	0-5080	145,000	5,720	100	100	100	86-0
6. Thames, Greenhithe . .	4	1-70	—	—	0-185	0-051	0-720	42,000	3,660	100	100	100	100
7. Itchen, Hants.	78	1-4	3-0	21-0	0-0034	0-0061	0-0692	3,270	137	100	98-7	41-0	2-5
8. Ouse, Beds.	115	2-1	8-3	29-5	0-0077	0-0273	0-3259	11,930	360	100	96-5	50-9	2-4
9. Stour, Suffolk	100	2-6	8-0	34-0	0-0067	0-0216	0-246	8,100	242	100	93-0	39-0	8-0
10. Kennet, Berks.	69	1-5	5-2	22-8	0-0095	0-0179	0-2243	16,500	3,560	100	97-1	85-3	46-3
11. Bure, Norfolk	20	4-5	6-5	24-0	0-0086	0-0535	0-512	3,520	192	100	90-0	40-0	5-0
12. Cefnog, Wales	5	0-9	1-0	1-5	0-0052	0-0092	0-125	1,400	19	100	100	0	0
13. Chelmer, Essex	160	3-9	9-0	27-5	0-026	0-083	0-320	11,500	1,200	100	88-0	60-0	9-0
14. Blackwater, Essex . . .	150	4-6	7-5	28-5	0-012	0-026	0-312	9,600	980	100	92-0	56-0	23-0
15. Avon, Hants	18	1-5	6-0	22-2	0-0043	0-0136	0-1966	6,590	101	100	88-8	61-1	0
16. Tees, Durham	30	0-95	3-0	8-0	0-0036	0-0137	0-579	5,040	370	100	90-0	63-3	10-0
17. Severn, Worcester . . .	12	3-8	8-0	16-0	0-0172	0-0346	0-418	30,400	1,690	100	100	100	63-0
18. Avon, Warwick	25	1-9	8-0	22-0	0-0078	0-0274	0-363	5,900	543	100	72-0	52-0	12-0
19. Chess, Bucks.	16	1-1	4-0	24-5	0-0606	0-0078	0-077	4,100	256	100	75-0	50-0	0
20. Dee, Chester	30	1-7	4-5	6-7	0-0238	0-0200	0-337	17,500	1,720	100	100	100	25-0
21. Dee, Wales	14	0-9	1-5	1-6	0-0035	0-0104	0-268	2,470	269	100	93-0	50-0	0
22. Eden, Surrey	36	3-35	8-0	14-0	0-1480	0-029	0-373	8,400	340	100	100	76-0	36-0
23. Otter, Somerset	24	1-15	3-0	4-5	0-0084	0-0149	0-195	2,730	260	83-0	54-0	21-0	4-0
24. Little Avon, Glos. . . .	35	1-9	6-3	25-5	0-0085	0-0220	0-300	4,120	474	100	88-0	74-0	39-0

A very good type of river water, fed largely by springs in the Chalk, is represented by No. 7. The water has the main characters of chalk water, is sparkling in appearance, rich in algæ and other life, and of relatively good organic quality. The samples were collected within a few miles of the tidal reaches, and the bacterial results show the effects of pollution by drainage from grazing land.

There are several rivers in the south of England with chalk waters of this type, capable of supplying a large population with water. Softening and purification is readily effected, and an excellent water is produced. The River Itchen water, after purification and softening, is, for example, used to augment the public water supply to Southampton.

A typical upland, highly-coloured, peaty river water is shown in No. 16. This river is polluted, and the water is purified by filtration and chlorination before use for public supply purposes.

A typical mountain stream water is shown in No. 12. The water is acid in reaction, very soft, and receives some slight sewage pollution from habitations along its banks.

No. 21 is a similar case, and lower downstream this river water, after purification, is utilised for public supply purposes (see No. 20).

Slow-flowing rivers passing through agricultural land are demonstrated in Nos. 8, 9, 10, 11, 13 and 14. These all provide water supplies to various districts.

A general survey of this Table indicates that river waters in this country are, as a whole, subject to contamination and require careful treatment to render them fit for drinking purposes. They mostly receive sewage or effluents, and are therefore potentially or actually disease-carrying waters.

Much avoidable pollution undoubtedly takes place and urgent measures are necessary to minimise this danger, since rivers must provide an ever-increasing proportion of our future public water supplies.

As will be shown in subsequent pages, modern methods of purification are capable of rendering most inland river waters pure and wholesome in character, but there is a limit to the degree of pollution which can be effectively and economically dealt with at a waterworks.

In addition to domestic sewage, much trade-waste is discharged into rivers, and this may prove very troublesome. The waste from sugar-beet factories is an instance of this kind in which odour and taste are imparted to the water and resist removal by ordinary methods of treatment. Certain waterworks authorities have experienced considerable difficulty on this account, and treatment by activated carbon has proved the only efficient remedy.

River-derived waters as a whole, apart from the chalk water rivers, even when most efficiently purified, are usually characterised by a lack of sparkle and a flatness of taste, compared with water derived from deep sources. The excess-lime method of treatment produces a better result in this respect than other processes applied to river waters.

Ozonisation also is beneficial in improving brightness and palatability.

(4) **Springs.** It is often supposed that "spring water" is pure. This is sometimes true, but, in our experience, it more often is not, as will be seen from a perusal of Table VII, which is a summary, compiled from our records, of analyses of fifty samples of water collected from different springs.

It will be seen that only 30 per cent. of these samples were free from *Bact. coli* in 100 c.c., and no less than 58 per cent. contained *Bact. coli* in 10 c.c. or less.

TABLE VII
SUMMARY OF THE ANALYSES OF SAMPLES OF WATER FROM
FIFTY SPRINGS

Chemical Results in Parts per 100,000.	Highest.	Lowest.	Average.
Chlorine in chlorides	12.5	1.3	3.27
Hardness : Permanent	30.0	2.0	7.8
Total	56.0	2.0	23.1
Free ammonia	0.0688	0.0006	0.0040
Albuminoid ammonia	0.2150	0.0004	0.0110
Oxygen absorbed from permanganate in 3 hours at 37° C.	0.385	0.002	0.0634
No. of bacteria per c.c. on gelatin in 3 days at 20° C.	12,000	5	1,007
No. of bacteria per c.c. on agar in 1 day at 37° C.	1,800	1	73
70 per cent. of samples containing <i>Bact. coli</i> in 100 c.c. or less.			
58 " " " " " " " "	" "	10 c.c.	"
20 " " " " " " "	" "	1 c.c.	"
8 " " " " " " "	" "	0.1 c.c.	"

Spring water may vary considerably in quality, depending on geological and topographical conditions. The water may be hard or soft, pure or polluted, or sometimes saline, sulphurous, ferruginous, etc.

The yield from springs is mostly inadequate, except for small supplies. The largest spring supply in England is that of Portsmouth, which derives its water from a number of springs, arising at Havant and Bedhampton, and having an average daily yield of approximately 20 million gallons.

These springs, like many others, are subject to fluctuation in yield and disturbance by rainfall, and a few observations concerning them are of interest. The water emerges from the Chalk at the edge of its outcrop from under a thick bed of London Clay and Reading Beds, and has the characters of a typical chalk water. In spite of the fact that the water rises to the surface from a depth of 300 or more feet, it is of variable purity, and the average limits of variation observed over a long period of time are shown in Table VIII. Fissures and swallow-

holes in the exposed Chalk some miles distant from the springs are responsible for this variation in character. Purification is carried out by chlorination and slow sand filtration with excellent results.

TABLE VIII
SHOWING THE QUALITY OF THE WATER YIELDED BY SPRINGS AT
HAVANT AND BEDHAMPTON, HANTS

Parts per 100,000.	Raw Water.			Purified Water. Averages 78 Samples.
	Averages 192 Samples.	After Heavy Rainfall, 1½ inches.	During Drought, One Month without Rain.	
Total solids . . .	28.5	26.0	29.0	29.0
Chlorine . . .	1.7	2.0	1.7	1.7
Total hardness . . .	22.0	18.0	22.5	22.5
Nitric nitrogen . . .	0.3	0.3	0.3	0.32
Free ammonia . . .	0.0020	0.0032	0.0010	0.0010
Albuminoid ammonia . . .	0.0045	0.0130	0.0008	0.0010
Oxygen absorbed 3 hours at 37° C.	0.053	0.213	0.010	0.015
Bacteria per c.c. on gela- tin in 3 days at 20° C.	760	Over 16,000	106	21
Bacteria per c.c. on agar in 1 day at 37° C. . .	54	4,000	2	4
Bact. coli c.c.	$\left\{ \begin{array}{l} +100 \quad 99\% \\ +10 \quad 87\% \\ +1 \quad 27\% \\ +0.1 \quad 2\% \end{array} \right\} + 0.1 \text{ c.c.} - 100 \text{ c.c.}$			- 100 c.c. in all samples.

Spring waters, when not disturbed by rainfall, are often attractive in appearance and of good palatability. The content of free carbonic acid is sometimes high, and the water may possess corrosive and plumbo-solvent properties.

(5) **Shallow Wells.** Shallow wells, like other sources, yield waters of widely varying character, and, as a class, they are of a low grade of bacterial purity. Shallow wells are seldom used for public water supplies, and the majority of samples of such waters examined in the laboratory are derived from wells supplying country houses, farms, etc., where no public water supply is available. Properly constructed wells dug in sites remote from sources of pollution may yield satisfactory waters, but more often the well is situated in close proximity to cess-pools, farmyards, etc., and sewage or manurial pollution frequently occurs.

Our experience of numerous shallow wells has led us to regard all such waters as contaminated till the contrary is proved. They are notoriously liable to intermittent pollution, and samples of water should always be collected after heavy rainfall, when marked deterioration in purity may be revealed.

A series of analyses from 100 shallow wells, practically all supplying individual houses, cottages, and farms in rural districts, is shown in Table IX.

It will be noted that the average standard of organic purity is low, the average bacterial content is high, only 26 per cent. of the samples are free from *Bact. coli* in 100 c.c., and 55 per cent. contain this organism in 10 c.c. or less of water.

TABLE IX
SUMMARY OF THE ANALYSES OF SAMPLES OF WATER FROM
100 SHALLOW WELLS

Chemical Results in Parts per 100,000.	Highest.	Lowest.	Average.
Chlorine in chlorides	52.0	0.8	7.15
Hardness : Permanent	125.0	2.0	17.0
Total	130.0	5.5	21.6
Free ammonia	0.3900	0.0006	0.0148
Albuminoid ammonia	0.1100	0.0004	0.0115
Oxygen absorbed from permanganate in 3 hours at 37° C.	1.800	0.005	0.130
No. of bacteria per c.c. on gelatin in 3 days at 20° C.	Over 100,000	2	2,900
No. of bacteria per c.c. on agar in 1 day at 37° C.	11,000	1	266
74 per cent. of samples containing <i>Bact. coli</i> in 100 c.c. or less.			
55 " " " " " " "	" "	10 c.c.	"
25 " " " " " "	" "	1 c.c.	"
5 " " " " " "	" "	0.1 c.c.	"

Shallow well waters often give a high figure for nitrogen in nitrates, and we have found as much as 19 parts per 100,000. Such highly nitrated waters are frequently brilliantly clear, and very palatable. A point of importance with regard to hard (permanent hardness), highly-nitrated waters from shallow wells is the marked plumbo-solvent property which they frequently possess. In Essex, Surrey, and elsewhere, a number of shallow well waters of this type occur, and have caused severe plumbism.

(2) Deep Sources

Deep Wells and Boreholes. Deep wells and boreholes provide the water supplies to many communities, and often yield waters of the highest degree of organic and bacterial purity. Such waters are therefore sometimes supplied to the consumers in their natural and untreated state.

When treatment is necessary it is usually for such purposes as softening or the removal of iron. There are, however, many instances

TABLE X
SUMMARY OF THE ANALYSES OF SAMPLES OF WATER
FROM FIFTY BOREHOLES

Chemical Results in Parts per 100,000

Geological Formation.	Chlorine in Chlorides.	Permanent Hardness.	Total Hardness.	Free Ammonia.	Albuminoid Ammonia.	Oxygen Absorbed.	Bacteria per c.c.		Bact. Coll.
							Gelatin. 3 Days.	Agar 1 Day.	
<i>Chalk.</i>	10.2	8.5	31.0	0.0016	0.0004	0.005	5	1	c.c. -100
	3.2	4.5	19.0	0.0018	0.0004	0.005	40	4	-100
	2.3	6.0	32.0	0.0018	0.0008	0.010	36	3	-100
	2.5	11.0	34.0	0.0016	0.0004	0.005	13	2	-100
	1.6	6.0	26.5	0.0016	0.0008	0.015	12	0	-100
	2.3	4.0	32.0	0.0014	0.0008	0.015	11	2	-100
	1.4	4.5	28.0	0.0018	0.0006	0.010	36	2	-100
	1.2	4.0	27.0	0.0008	0.0008	0.015	62	1	-100
	1.9	5.0	28.0	0.0008	0.0004	0.005	7	5	-100
	5.4	6.0	27.0	0.0390	0.0016	0.020	26	3	-100
	1.4	3.0	19.0	0.0006	0.0004	0.005	9	2	-100
	1.4	3.0	26.5	0.0028	0.0008	0.015	25	1	-100
	2.0	7.0	28.0	0.0016	0.0004	0.005	7	1	-100
<i>London Clay.</i>	4.5	2.0	20.0	0.0680	0.0024	0.050	1500	19	-100
<i>Chalk under London Clay.</i>	2.2	4.5	16.0	0.0880	0.0016	0.025	32	2	-100
	8.1	2.5	22.0	0.0520	0.0040	0.010	30	1	-100
<i>Chalk under Thane Sand and London Clay.</i>	33.0	0.0	12.5	0.0980	0.0012	0.020	40	1	-100
	30.0	0.0	2.5	0.0660	0.0032	0.050	4	1	-100
	28.0	0.0	3.0	0.0590	0.0032	0.050	9	3	-100
	13.0	0.0	7.5	0.0570	0.0052	0.075	130	4	-100
	12.4	0.0	6.0	0.0800	0.0010	0.005	120	3	-100
	8.8	0.0	5.0	0.0580	0.0170	0.057	180	4	-100
	9.7	0.0	7.5	0.0490	0.0012	0.030	116	8	-100
	47.5	0.0	5.5	0.1080	0.0018	0.030	6	4	-100
	14.5	0.0	7.0	0.0480	0.0020	0.030	160	5	-100
	12.5	0.0	6.5	0.0410	0.0006	0.010	73	2	-100
	12.3	0.0	7.0	0.0600	0.0000	0.002	120	12	-100
	54.0	0.0	11.0	0.0640	0.0040	0.040	550	8	-100
<i>Lower Green-sand.</i>	5.2	0.0	7.5	0.0240	0.0006	0.010	25	2	-100
	1.6	2.0	12.0	0.0016	0.0012	0.010	10	4	-100
	5.4	0.5	7.0	0.0140	0.0006	0.010	3	0	-100
	4.1	0.0	8.0	0.0180	0.0002	0.005	78	2	-100
<i>Wealden Clay</i>	16.5	0.0	1.0	0.0810	0.0024	0.040	5	0	-100
<i>Hastings Beds.</i>	5.0	8.0	13.0	0.0032	0.0016	0.030	20	0	-100
	2.6	0.0	4.0	0.0220	0.0010	0.045	110	2	-100
	2.9	1.0	6.0	0.0024	0.0008	0.010	76	2	-100
<i>Oolite.</i>	1.8	8.0	26.0	0.0004	0.0012	0.020	3	1	-100
<i>Coal Measures.</i>	2.2	50.0	75.0	0.0210	0.0026	0.050	30	2	-100
	5.7	8.0	48.0	0.0072	0.0032	0.055	960	270	-100
<i>New Red Sandstone.</i>	3.0	8.0	28.0	0.0018	0.0008	0.015	20	1	-100
	6.4	0.0	3.0	0.0330	0.0016	0.025	86	2	-100
	2.4	7.0	10.0	0.0036	0.0006	0.005	78	4	-100
	1.9	0.0	18.0	0.0180	0.0020	0.085	140	1	-100
	2.8	13.5	14.0	0.0024	0.0018	0.025	5	2	-100
	2.6	8.0	26.0	0.0020	0.0008	0.015	4	1	-100
	2.4	15.0	43.0	0.0032	0.0028	0.080	4	1	-100
	3.4	12.0	36.0	0.0024	0.0012	0.020	6	1	-100
	18.8	3.0	21.0	0.1450	0.0010	0.015	21	1	-100
	11.2	27.0	52.0	0.0310	0.0008	0.015	9	3	-100
	70.0	154.0	160.0	0.0120	0.0004	0.010	126	3	-100

of bacterial pollution of deep wells, particularly when situated in the Chalk or Limestone formations, and purification is required to render the waters suitable and safe for drinking and domestic purposes.

Many deep wells or boreholes, once affording adequate supplies, now prove insufficient in yield and resort has to be made to other sources, such as rivers, to meet the needs of the district. The water level in the Chalk of the London Basin is, for example, falling year by year and the yield of many boreholes sunk therein is now so small that pumping has been discontinued.

The Chalk is, however, still an important water-yielding formation, and yields many ample and excellent supplies.

The quality of a number of borehole waters is shown in Table X and the analyses of many more are given in Chapter XXV.

Deep well and borehole waters, although often initially of exceptional bacterial purity, may show high bacterial counts when examined after storage in tanks or reservoirs, unless these are very effectively covered. Rapid multiplication of bacteria occurs, for example, in borehole waters containing appreciable sodium salts in solution, such as those of the London Basin, although such waters may be of excellent organic purity.

Pollution of borehole waters may, however, take place, and the following are examples of the ways by which this may occur. Such formations as the Chalk, Limestone and Sandstone are liable to fissures which may extend to great depths and open at the surface. Therefore, where the surface of the water-bearing formation is exposed or inadequately covered, polluted surface water may pass directly down the fissures to the deep water. Abandoned boreholes, wells and mine-shafts, may also provide the means of direct access of surface matter to the deep water.

Surface water may also gain access to boreholes over the top of the tube, particularly when situated in a sump, by trickling down the outside of the tube, and by fractures of the tube, or perforations caused by corrosion.

Air-lift pumps may add dust and bacteria to the water unless clean air is drawn, or is efficiently filtered. The packing sometimes used in pumps is heavily contaminated with bacteria, including coliform bacteria, and the water may be affected thereby. Instances occur where the drainage of pump sumps is deliberately returned to the well. This return should be prevented, and arrangements made for the external drainage of the sump.

We have known all the above to be responsible for the bacterial pollution of borehole waters, and, after removal of the cause, a long period of time often elapses before the water recovers its original purity. In one instance where, owing to a flood, the pump sump filled with river water, and drained down the bore, a period of twelve months' pumping was required before the water regained its former purity. The development of growth and slime on the walls of a well or borehole may prove troublesome and difficult to remove. Growths of iron-

bacteria and other fungi sometimes become established in boreholes, and give rise to complaints by subsequent proliferation in mains and reservoirs. Several such cases have been remedied by the addition of sodium hypochlorite solution to the borehole, and subsequent pumping to waste.

Borehole waters are often clear and bright, but, in other cases, they are ferruginous, or may contain suspensions of chalk, sand, clay, etc.

It is not unusual for boreholes to deliver water having an odour of sulphuretted hydrogen, which, as a rule, is readily dissipated on exposure to the atmosphere, or by aeration. This odour does not indicate an impure or unwholesome condition, and is frequently observed in water derived from the Chalk, in London, Essex, and elsewhere.

The majority of deep waters are neutral in reaction, but some exceptions occur. The ferruginous waters derived from the Hastings Beds, for example, may be faintly acid in reaction (pH 5.5 to 6.0), while those obtained from the Chalk and Thanet Sand beneath the London Clay are faintly alkaline (pH 8.5). The latter waters are aggressive to iron and steel, but are not plumbo-solvent.

The palatability of deep waters is, on the whole, good, particularly those from the Chalk, but the soft alkaline waters tend to be insipid.

It is customary to speak of "chalk waters" though the Chalk yields waters of many different kinds. Some are hard, neutral in reaction, and contain little but chalk in solution, and this is the type referred to as a typical chalk water. Others are soft, alkaline in reaction, and most of the matter in solution consists of sodium salts. Also, there are chalk waters which are brackish and others which are ferruginous.

Deep waters contain little nitrogenous matter, but some, derived from the Chalk in Hertfordshire and elsewhere, are found to contain 1 to 2 parts per 100,000 of nitrogen in nitrates. Samples sometimes show traces of nitrites, which may be produced by the reduction of nitrates by the metals of bore tubes, pumps, and pipes with which the water comes in contact.

The albuminoid ammonia and oxygen absorbed from permanganate are generally low, but free and saline ammonia may be high. The latter is common to many borehole waters, particularly those of the Thanet Sand and Chalk beneath the London Clay, and is not an indication of pollution.

On many occasions, excellent borehole waters have unjustifiably been condemned as polluted solely on account of a high figure for free and saline ammonia, or the presence of nitrites.

Standards of Purity for Borehole Waters. Except in certain cases of which mention has been made, borehole waters contain very few bacteria, and it is customary to find under 10 per c.c. growing on agar in one day at 37° C. *Bact. coli* should be absent in 100 c.c., and a positive result, even in this quantity of water demands investigation.

Streptococci and *Cl. welchii* spores should also be absent in 100 c.c.

We have on several occasions received the first warning of con-

tamination of a deep water by obtaining a positive *Cl. welchii* reaction in 100 c.c., and this has invariably been confirmed by the presence of *Bact. coli* in subsequent samples.

(3) Purified Waters

The analyses of many samples of natural waters have been given, and those of waters purified by ordinary waterworks processes will now be described.

Twelve representative examples, all of large public supplies, deriving waters from different sources and treated by various methods, have been selected. The results of over 1,800 samples of the raw and treated waters of these twelve supplies are tabulated in Table XI. Perusal of these results shows the efficiency of modern methods of water purification particularly from the bacteriological standpoint. It will be seen that, in this respect, polluted river waters are rendered of the highest standard of purity. This is achieved by a combination of processes of which chlorination is not the least important, for this measure is now employed at almost all waterworks where polluted waters are purified. The Table also shows (No. 12) the excellent results obtained by the "excess-lime" process.

In addition to the figures given in the Table, there are other items that concern the suitability of a water for drinking and domestic purposes, such as clarity, palatability, hardness and corrosive action on metals, and these several points should receive due consideration in every supply.

The removal of suspended matter and colour is usually achieved by storage, the addition of coagulants, sedimentation, and sand filtration.

River-derived supplies are often insipid and may retain definite earthy or musty odour after careful purification by efficient methods. The use of activated carbon or ozonisation is efficacious in removing such odour and taste, and also in improving the clarity of the final waters. Odours and tastes produced by chlorination can be removed by similar means.

Many river waters are hard in character and neutral in reaction, but others, such as most upland and moorland streams, are soft and faintly acid. Lime is often added to the latter in order to restrain their plumbosolvent and corrosive properties. The "excess-lime" process is particularly valuable for the purification of hard polluted waters, owing to the removal of temporary hardness which takes place.

A few notes with reference to the supplies illustrated in Table XI will be of interest:—

No. 1. This is a spring supply of 10 to 15 million gallons a day, subject to bacterial impurity and slight turbidity after rainfall. It is treated successfully by a dose of chlorine varying from 0.25 to 0.5 part per million, followed, after one hour's contact, by slow sand filtration at a rate of 3 million gallons per acre per day.

No. 2. This is a hard water derived from deep wells in the Chalk. Chemical analysis shows no evidence of pollution, but *Bact. coli* is

invariably found in the water. The treatment consists of Clark's process of softening and chlorination.

No. 3 is a similar though more impure water treated by the same processes as in No. 2.

No. 4 is a river water mixed with well water, and purified by slow sand filtration (rate of 1 million gallons per acre per day) and chlorination.

No. 5 is a case where superchlorination with dechlorination was preferred owing to the inefficiency of the slow sand filters. Coagulant treatment, sedimentation and rapid sand filtration have now replaced slow sand filtration.

No. 6 is a supply derived from the River Thames, and treated by rapid sand filtration, followed by slow sand filtration and chlorination. There is no raw water storage, but the results are consistently satisfactory.

No. 7. There is also no raw water storage in this case, but a dual system of filtration is employed, followed by ammonia-chlorine treatment. The free ammonia is often higher, therefore, in the treated water than in the raw.

No. 8. This is a highly coloured peaty water of upland origin, and little colour is removed by treatment. Coagulants and rapid filters would be a better form of treatment for this water than slow sand filtration. Note the high oxygen absorbed figure, and the chlorine dose required is similarly high (1 to 2 parts per million after filtration).

The results obtained by the "excess-lime" process are shown in Nos. 11 and 12. The final waters compare very favourably with those of other processes and have the advantage of being partially softened. Six million to ten million gallons of water are treated daily at these two plants.

Study of Table XI shows that the bacterial results achieved in the purification of polluted waters from rivers, etc., compare favourably with those given by the most satisfactory well waters. Pollution of the sources must, however, be restricted to a minimum, otherwise the limit may be reached above which a water cannot be economically and efficiently purified.

A long and varied experience of river-derived water supplies has convinced us that, with properly selected intakes, and well-designed and carefully operated purification plants, a final water can be obtained which is pure and wholesome in character and suitable for the purposes of a public supply.

Standards of Purity for River-derived Supplies. The results shown in Table XI are typical of those obtained without undue difficulty, and the Reports of the Director of Water Examinations to the Metropolitan Water Board show an equally satisfactory condition in the case of London's river-derived supplies. It will be seen that the number of bacteria growing on agar in one day at 37° C. is usually below 10 per c.c., and on gelatin in three days at 20° C. below 100 per c.c. Also, that *Bact. coli* is absent in 100 c.c. in the great majority of samples. Usually

TABLE XI

SHOWING RESULTS OBTAINED IN THE PURIFICATION OF POLLUTED WATERS. PUBLIC WATER SUPPLIES. AVERAGES
CHEMICAL RESULTS IN PARTS PER 100,000

Description of Supply.	Number of Samples.	Nitrogen in Nitrates.	Free Ammonia.	Albuminoid Ammonia.	Oxygen Absorbed in 37° C. Hours.	Agar Count 1 Day. 37° C.	Gelatin Count 3 Day. 20° C.	Percentage of Samples containing Bact. Coll. in.				0-01 c.c. or less.
								100 c.c. or less.	10 c.c. or less.	1 c.c. or less.	0-1 c.c. or less.	
1. SPRINGS	R. 118	0-32	0-002	0-0045	0-053	26	580	100	87	16	2-5	—
Slow sand filtered and chlorinated	F. 118	0-32	0-001	0-001	0-015	3	17	0	—	—	—	—
2. DEEP WELLS IN CHALK	R. 22	0-68	0-0002	0-0012	0-007	9	51	100	77	14	0	—
Softened and chlorinated	F. 22	0-68	0-0002	0-0010	0-006	1	5	0	—	—	—	—
3. DEEP WELLS IN CHALK	R. 23	0-45	0-0061	0-0034	0-032	16	250	100	69-5	35	4	—
Softened and chlorinated	F. 23	0-41	0-0017	0-0011	0-017	4	31	4-3	0	—	—	—
4. MIXED WELL AND RIVER WATER	R. 51	0-16	0-0037	0-0120	0-145	124	4,159	100	90-0	40	2	—
Slow sand filtered and chlorinated	F. 43	0-16	0-0019	0-0076	0-102	5	53	34-8	0	—	—	—
5. RIVER WATER	R. 25	0-13	0-0078	0-0274	0-363	543	5,900	100	100	72	52	12
Slow sand filtered, chlorinated and dechlorinated	F. 50	0-12	0-0037	0-0178	0-290	6	93	0	0	—	—	—
6. RIVER WATER	R. 100	0-24	0-0088	0-0211	0-332	1,120	9,210	100	100	96	79	30
Primary and secondary filtration and chlorination	F. 100	0-27	0-0029	0-0073	0-106	7	39	2	0	—	—	—
7. RIVER WATER	R. 18	0-22	0-0048	0-0136	0-1966	101	6,590	100	100	88-8	61-1	0
Primary and secondary filtration and chloramination	F. 60	0-22	0-0049	0-0075	0-106	4	48	5	0	—	—	—
8. RIVER WATER—Peaty	R. 30	0-03	0-0036	0-0137	0-579	370	5,040	100	100	90	63-3	10
Slow sand filtered, stored and chlorinated	F. 27	0-08	0-0021	0-0131	0-713	24	597	30	0	—	—	—
9. RIVER WATER	R. 207	0-23	0-0081	0-0234	0-279	477	9,400	100	100	94-5	69-9	11-5
Primary and secondary filtration and chlorination	F. 62	0-25	0-0033	0-0080	0-105	9	80	6-4	1-6	0	—	—
10. RIVER WATER	R. 30	0-11	0-0238	0-0200	0-337	1,720	17,500	100	100	100	100	25
Primary & secondary filtration & chlorination	F. 22	0-10	0-0014	0-0105	0-187	6	14	0	—	—	—	—
11. RIVER WATER	R. 150	0-25	0-019	0-0295	0-316	1,100	10,500	100	100	85	58	10
Stored, Alumina, excess lime and rapid filtration	F. 150	0-24	0-0022	0-0062	0-072	1-5	19	0	—	—	—	—
12. RIVER WATER	R. 150	0-22	0-026	0-033	0-320	1,200	11,500	100	100	88	60	10
Stored, Alumina, excess lime and rapid filtration	F. 150	0-20	0-010	0-009	0-094	1-5	25	0	—	—	—	—

R = Raw Water.

F = Final Water.

the samples giving positive Bact. coli results have been those collected from the distribution services, *i.e.*, the water after passing through mains and reservoirs. Apart from water treated by the ammonia-chlorine process, it is customary to obtain better bacteriological results in samples collected at the waterworks than in samples procured from reservoirs or mains.

We suggest that the following standards should be aimed at and generally achieved in river-derived supplies, sampled at the delivery from the purification plant :—

Bacteria on agar, one day at 37° C. per c.c. Not exceeding 10.

Bact. coli : Absent from 100 c.c. in 90 per cent. of samples.

The presence at any time of Bact. coli in 10 c.c. or less of water would indicate unsatisfactory purification and inefficiency of the plant necessitating immediate attention.

The bacterial counts at 20° C. are less important, but figures of less than 100 are obtained with modern efficient purification plants.

Cl. welchii is resistant to treatment and, although reduction in number occurs, positive results in 100 c.c. are common in properly-filtered and chlorinated river waters. A positive result in 100 c.c. is, however, obtained less frequently in river water treated by the "excess-lime" process.

CHAPTER XXXVI

WATER SUPPLIES AND DISEASE

It is a generally accepted fact that the health of a community depends in large measure on the ample provision of a wholesome water supply. It is also true that much ill-health has been erroneously attributed to water supplies.

Illnesses of very varied character can be, and are, transmitted to man by water, and the causal agents conveyed by the water may be chemical poisons, pathogenic micro-organisms (bacteria, viruses and protozoa) and higher forms of parasitic life (*e.g.*, worms). Certain diseases have also been ascribed to the absence or deficiency of certain substances in the water supply.

Chemical Considerations

Acidity. In certain isolated stations of the Empire, where the only water available for drinking purposes is distilled sea-water, the distillate is so acid that neutralisation by chalk is necessary to prevent rapid and serious injury to the teeth of the consumers. In this country, acidity of water supplies is of importance in respect of action on lead pipes giving rise to plumbism.

Metals. Some of the metallic salts, if present in water, may be injurious to health. *Arsenic* should be absent. This metal may be present in some natural waters or may gain access to shallow wells from surface washings or percolation where arsenical weed-killers or tree-sprays have been used in the vicinity. Sheep-dipping may also contaminate stream waters with arsenic.

Lead is the commonest poisonous metal occurring in water supplies and has caused much ill-health in areas supplied (*via* lead pipes) with soft, acid, moorland and peaty waters. Very hard waters, with little or no bicarbonate hardness, a low *pH* value and a high content of nitrates, are also plumbo-solvent and may give rise to severe lead-poisoning. Lead pipes should not be used for the distribution of waters of these types. In districts where lead is mined, the metal is sometimes found in underground and surface waters. Streams may be seriously contaminated by washings from lead workings.

The typical symptoms of chronic lead poisoning are constipation, loss of appetite and abdominal pain associated with pains and tenderness of the muscles (principally of the arms) and a gradual paralysis which most commonly results in "wrist drop." There is also a degree of *anæmia*, and a blue line may sometimes be seen at the junction of the teeth and gums. These changes represent a relatively advanced

stage of plumbism, but it seems more than probable that a milder and often undiagnosed form is fairly prevalent in which the only symptoms may be lethargy, moroseness, constipation, flatulence and occasional abdominal pains.

We are unaware of any ill-health due to the presence of *copper*, *iron*, *manganese* or *zinc* in water. The amounts of these metals necessary to cause poisoning are such that objections on other grounds, *e.g.*, turbidity, discoloration, taste, etc., would prevent the consumption of the water. Some discussion has occurred with reference to the toxicity of *aluminium*, but there is no evidence of ill-health caused by the presence of this metal in water supplies.

Calcium, Magnesium and Sodium. Many unconfirmed statements have been made regarding the effects of calcium in water. Thus, the absence of calcium in soft waters has been considered responsible for rickets, defective teeth, etc., whereas the presence of calcium (and magnesium) salts in hard waters has been blamed for the occurrence of gout, rheumatism, urinary calculi, etc. In point of fact, there is no evidence to show that hard waters, even up to 50 parts per 100,000 of hardness, are more, or less, wholesome than soft waters, though hard waters are less suitable for certain domestic and industrial purposes. The amount of calcium imbibed, even in a hard water, forms only a small fraction of the daily calcium content of a well-balanced diet.

Waters containing relatively large amounts of magnesium or sodium sulphate may be purgative. Analysis No. 790, p. 406, shows a water which gave rise to widespread diarrhoea amongst the consumers.

Many boreholes in England, such as those of the London Basin, yield water comparatively rich in sodium salts (bicarbonate, sulphate and chloride—see Tables of Analyses, Chapter XXV). These waters are usually wholesome, and are much used for small local supplies. The water, (No. 549, p. 384), which contains 71 parts per 100,000 of sodium carbonate, was for many years used for drinking and general purposes and for the brewing of beer, without any complaint whatsoever. Although the high sodium content of these waters is not harmful, certain waters of this type are liable to contain objectionable amounts of fluorine, and this possibility should be considered before a new supply of this character is utilised for drinking.

Fluorine. "Mottled enamel," a developmental defect of the teeth, was first noted (Eager, 1901) among emigrants from Pozzuoli, Italy, and has since been observed to occur endemically throughout the world, notably in America and also in China, Africa, India, Spain, Italy, Holland and several small localised areas of England. From the time of the first recorded investigations (Black and McKay, 1916), suspicion was cast on the water supply, some abnormal constituent of which was believed to be the causal agent, but the exact nature of the latter was not discovered until 1931, when Churchill reported the presence of fluorine in the water supplies of various endemic areas in the United States, and Smith, Lantz and Smith (1931) reproduced the condition in experimental animals fed on diets containing (a) sodium fluoride, and

(b) the residue of the drinking water from an affected town. Ample evidence has since been forthcoming to confirm the responsibility of fluoride in drinking water for this condition in man, and similar effects have been noted in the teeth of domestic animals.

In North Africa, the presence of fluorine in the soil has been shown to cause bone disease, in addition to the dental defect, in horses and cattle; and both these conditions, together with signs of acute poisoning, have been exhibited by workers in aluminium factories where fluoride is present in the dust. Such severe effects are exceptional, however, and most cases of chronic fluorosis are limited to the teeth and are due to the continued ingestion during early childhood of small amounts of fluoride in the drinking water.

In mottled enamel (chronic endemic dental fluorosis) the damage is almost entirely confined to the permanent teeth, and occurs solely during the period of their calcification. Hence it is children up to the age of ten years who are susceptible, and the defect does not become manifest until after the teeth have erupted, *i.e.*, from the age of six years onwards. The teeth first lose their customary lustre and become chalky white; later they develop disfiguring patches of yellow, brown or black staining and may ultimately become pitted and absolutely black. The defect once established is permanent and incurable. One curious result is that teeth only mildly affected are more than normally resistant to decay, but those showing the grosser lesions are unduly brittle and soon deteriorate.

As little as 1 part per million of fluorine in water can cause the condition, but inadequate diet is said to play a contributory part. Waters containing less than 0.8 p.p.m. of fluorine appear to be harmless, in fact, in the U.S.A., minimal amounts are thought to be beneficial in preventing dental caries. Broadly speaking, the severity and incidence of the disease are proportional to the fluorine content of the water. Thus, waters containing 1 p.p.m. fluorine cause mottled enamel in 10 per cent. of the child consumers, whereas a concentration of 2 p.p.m. produces effects in 50 per cent. of the children. For the incidence to approach 100 per cent. the water must contain about 5 p.p.m. fluorine, and at such levels severe effects are present in 20 per cent. of cases (Dean and McKay, 1939). Though fluoride ingested in food can also exert a toxic action, the same quantity dissolved in water appears to be more harmful. This is probably because the salt, when dissolved in water, is more readily absorbed and stored by the body.

Geologically, fluorine is essentially an element of igneous origin and is most highly concentrated in volcanic depositions. From such sources, fluorine-containing minerals have been sparsely but widely distributed throughout the various sedimentary formations, but few of the latter appear to yield significant quantities of fluoride to water.

In America, much study has been devoted to the clinical aspects of dental fluorosis, but up to the present there is little information regarding the particular geological strata most probably responsible for the condition. The volcanic association is, however, well typified in Colorado

where fluoride is present in the surface water from Peak's Pike, a region which, according to Boissevan (1933), is as rich in fluorine minerals as is Vesuvius, on whose slopes Pozzuoli is situated. Similar conditions are found in neighbouring states, but in the remaining areas of U.S.A. the causative waters are most generally of deep origin (Dean, 1933). In Ohio, formations so far separated, geologically, as the Niagara Limestone (Silurian) and the Miocene are incriminated (Scott, Kimberly, *et al.* 1937; Maher, 1939).

Rock phosphate generally contains 3.5 per cent. of fluorine (Hart, Phillips and Bohstedt, 1934), and the effects described in North Africa have been shown to be due to superficial phosphatic strata contaminating the soil and surface water (Velu, 1931; Dean, 1935).

Dental fluorosis was first noted in this country by Ainsworth (1928 and 1933) who discovered it in the Maldon area of Essex, where the large majority of the children are affected and the water supply, derived from wells in the Lower London Tertiaries, contains approximately 5 p.p.m. of fluorine. Apart from the observations of Donaldson (1936) and a few leading articles in the *Lancet*, little has been published here on the subject until investigations were commenced by D. C. Wilson (1939), who states (1941): "I have studied the distribution of dental fluorosis amongst schoolchildren in Cumberland, Derbyshire, Durham and Westmorland in connection with fluorspar; in Somerset in connection with fluorine in limestone and lias clay; in Cornwall in china stone; in Bedfordshire and Buckinghamshire in the lower greensand; in the Marston valley of Bedfordshire and in Berkshire, Gloucester, Oxfordshire and Wiltshire in connection with the Oxford clay."

Wilson's researches are being assisted by the Geological Survey of Great Britain, and Bromehead states (1941) that the strata which most readily yield fluorine to water in this country are phosphatic beds and clays of marine origin, such as the Oxford Clay, the Lower Lias and the Kimmeridge Clay. Wells in such formations are (as Bromehead points out) usually of small yield, hence the trouble in this country is almost exclusively limited to small-yielding wells serving individual cottages or small villages. Our own investigations have satisfied us that the great majority of our public water supplies are free from objectionable amounts of fluorine. Thus, of the 340 waters listed in Table I, 252 contain less than 0.8 p.p.m. of fluorine, and 235 of these show no detectable trace of the element. Of the 88 remaining waters (all small public or private supplies), 80 are derived from the Lower London Tertiaries or the Chalk immediately underlying them, and 45 of these contain over 2 p.p.m. of fluorine. In our experience, therefore, the strata which most commonly yield water containing significant amounts of fluorine are the Lower London Tertiary Beds where these are covered by London Clay. Such conditions pertain at Maldon and other parts of Essex, where the deep well waters are soft and have a high sodium bicarbonate and chloride content. Our attention was drawn, several years ago, to similar circumstances in Tientsin, China, where deep boreholes sunk through a thick bed of clay into sands yielded water

of almost identical composition to that of Maldon and having an equally high fluorine content (5 p.p.m.). Several years after the use of these boreholes for public supply purposes, a river source having previously been used, the development of mottled teeth was noted amongst the child population.

While the geological picture is as yet far from clear, it would appear that, in this country at least, the fluoride which gains access to water is derived from one or other of the clays where these are in contact with water-bearing strata. It is only recently, however, that the

TABLE I
FLUORINE CONTENT OF WATER SUPPLIES IN ENGLAND

Sources.	Total number of waters.	Number of waters having a fluoride content in p.p.m. of fluorine:				
		0.0.	0.0 - 0.8.	0.8 - 2.0.	2.0 - 5.0.	5.0 +.
Rivers, etc. . . .	30	30				
Shallow wells . . .	25	23	1 (a)	1 (a)		
Lower London Tertiaries . . .	30				5	25
Chalk under Tertiaries . . .	70	5 (b)	15	35	15	
Chalk outcrop . . .	80	80				
Greensand . . .	40	40				
Hastings Beds . . .	10	10				
Oolites . . .	20	16	1	3 (c)		
New Red Sandstone . . .	20	18		2 (d)		
Coal Measures . . .	10	8		2 (e)		
Older Rocks . . .	5	5				
TOTALS . . .	340	235	17	43	20	25
		252		88		

(a) Both from Boulder Clay.

(b) All from Chalk near outcrop (*i.e.*, where Chalk covered by only a thin layer of Tertiaries).

(c) All from Oxford Clay.

(d) Both from the Bunter formation.

(e) Both from mine waters, in which the total solids and the fluorine content increase on pumping.

problem of dental fluorosis has received official consideration in this country, and though Wilson has shown the condition to be more widespread than was formerly believed, the incidence is fortunately very low.

Workers in the United States have devoted much attention to the possibility of removing fluoride from water and various methods have been proposed. Of these, treatment by tri-calcium phosphate appears to be most favoured, but usually the final result has been the provision of an alternative source of water supply. This latter course has proved well worth while and is the obvious remedy in this country.

Deficiency of Salts, etc., in Water. Allegations are sometimes made that a deficiency in water supplies of certain substances, such as calcium or iodine is detrimental to health, and we have, for example, known opposition to municipal softening on such grounds. Even sterilisation of water is sometimes criticised for similar reasons. Such views cannot be upheld, and in our opinion, essential food substances or accessory factors are properly supplied in an adequate and well-balanced diet, quite apart from water. This duty should not be included in the functions of a Water Authority.

Treated Waters. In other pages of this work the occasional presence in purified water supplies of odours and tastes, such as musty, earthy, iodoform, etc., has been discussed. These flavours are objectionable and can often be prevented, but do not necessarily render the water injurious to health. Also, there is no reason to believe that small traces of free chlorine or chloramine in treated waters are unwholesome, though cases of allergy to chlorine have been recorded in America. It is prevailing practice as a war-time measure to distribute water containing residual chlorine or chloramines in larger amount than formerly, and reactions of 0.2 to 0.5 parts per million are common but no ill-effects on health have been recorded, although complaints of chlorinous odour and taste are not infrequent.

Certain authorities have regarded as harmful the presence of organic matter in water, but we know of no evidence to support this view. An undue amount of organic matter in water has, however, other disadvantages and should preferably be removed by the processes of treatment employed.

Diseases due to Bacteria

The gravest of all dangers to which water supplies are exposed is infection by pathogenic bacteria of which typhoid bacteria are now the most important in this country. The efforts of Water Undertakers must, therefore, be primarily directed to ensure bacterial purity of the supplies by all available means, including protection of the sources, treatment of the waters, and care in handling and distribution.

Bacterial diseases which may be spread by water include enteric fever, cholera, dysentery and gastro-enteritis. Infections by *Salmonella* bacteria other than *Bact. paratyphosum B* and the leptospiræ of epidemic jaundice (Weil's disease) are other possible but infrequent risks. The micro-organisms of all of these diseases are discharged by patients or *carriers* in the excreta, either urine or fæces, and hence it is against such contamination, however minute, that water supplies must be particularly protected. Some, such as enteric fever, are exclusively human diseases, but in others, *e.g.*, Weil's disease, the infecting organism may be derived from animal excreta.

Enteric Fever. This includes both typhoid and paratyphoid fever, the former being caused by *Bact. typhosum* and the latter by *Bact. paratyphosum*. These bacteria are easily distinguished from one

another (see Chapter XXXIII), but the distinction was not made until 1896, prior to which date both typhoid and paratyphoid fever were described as enteric fever. This fact must be remembered in reviewing records of past epidemics.

There are three known varieties of paratyphoid fever caused by *Bact. paratyphosum* A, B and C respectively, but only one of them, *i.e.*, *Bact. paratyphosum* B, is of importance in this country.

Enteric fever is contracted *via* the mouth by the medium of food (including milk) or water contaminated with typhoid or paratyphoid bacteria. Water is usually implicated in large outbreaks of typhoid fever, but contaminated food is apparently now more often responsible for small outbreaks and for paratyphoid fever. In the Ministry of Health "Memorandum on Typhoid Fever," Memo. 225/Med., it is stated "Sporadic cases occurring weeks apart but reappearing year by year in a district and giving the appearance of endemicity, may be due to the repeated specific pollution of a water supply and the 'endemicity' ceases with the discontinuance or purification of the supply."

Human dejecta are the primary vehicles of the infecting bacteria, food or water may be the secondary and final vehicle, or there may be a third stage in the dissemination. Thus, shell-fish or water-cress might be the foods immediately responsible, but these would acquire the enteric bacteria from the water in which they had been cultivated, and this in turn would receive them from human excrement or sewage.

Similarly, milk may spread the disease, having acquired the bacteria from sewage-polluted water used for the watering of cattle, the cooling of milk or the washing of dairy utensils. Water thus plays direct and indirect parts in the spread of enteric fever. The Croydon typhoid fever outbreak (1937) was an example of direct spread by drinking water and the Bournemouth typhoid fever epidemic (1936) was one in which polluted water from a stream played an indirect part, milk being the final vehicle. The sequence of events leading to the Epping paratyphoid fever outbreak (1931) was similar to that at Bournemouth, *i.e.*, sewage, stream water, milk.

No animal is known to suffer from typhoid fever or naturally to harbour the bacteria. Man alone perpetuates the disease, and in outbreaks the infecting bacteria may be derived either from a patient or from a *carrier*. The enteric *carrier* is a person apparently in good health who nevertheless excretes in the urine, or faeces, or both, typhoid or paratyphoid bacteria. As a general rule *carriers* have previously suffered from enteric fever, but the disease may not have been diagnosed, or the attack was so mild that the patient did not take to bed or consult a physician. Hence a *carrier* may be in ignorance of his condition and honestly disclaim any history of enteric fever. *Carriers* are very dangerous to the community unless suitably instructed and conscientious in observing the strictest cleanliness and personal hygiene. They should never be engaged in the preparation or handling of food or drink nor employed on a waterworks.

In every outbreak of enteric fever a small percentage of the patients

become *carriers*. Of these, some are temporary *carriers*, the excretion of enteric bacteria in the urine or faeces ceasing within a year of convalescence. Others (2-4 per cent.) however, become permanent or chronic *carriers* and excrete typhoid or paratyphoid bacteria continuously or intermittently for the remainder of their lives. No easy and certain cure for the condition has yet been found and its discovery would greatly assist in the eradication of typhoid fever. A vicious circle would then be broken, since the higher the incidence of typhoid fever, the greater is the percentage of *carriers* in the community, and the more *carriers* there are, the greater are the potential risks of further outbreaks. The percentage of chronic *carriers* in the population of this country is unknown, but it is doubtless very small, variable in different localities, and on the average only a small fraction of 1 per cent.

Efficient sanitation, strict personal hygiene and the protection of water and foods from excremental contamination are the methods relied on to prevent enteric outbreaks arising from *carriers*. Spread from patients is prevented by early diagnosis and careful medical treatment and nursing, but the ambulatory case is a particular danger, especially in paratyphoid fever. Immunisation of the populace is also a valuable preventive measure.

The degree of care which must be exercised in respect of enteric patients and *carriers* is very high. Thus, the number of typhoid bacteria present in the faeces or urine of either may be hundreds of millions per gram or cubic centimetre. One drop of such material gaining access to a service reservoir, for example, may introduce ten millions or more of typhoid bacteria; hence, assuming uniform dispersal in, say, one million gallons of water, there would be at least one typhoid bacterium in each pint of water consumed. Unless the water contained a disinfectant such as free chlorine or chloramine, these bacteria might remain viable for several weeks of storage (see Chapter XXXIII) and cause widespread disease among the consumers. Theoretically, the ingestion of one bacterium could cause the disease, but, in practice, such is probably very seldom the case. Of many persons exposed to the same risk, some contract the disease in serious form, others only mildly and still more escape altogether. In the Croydon typhoid outbreak, for example, not more than 0.75 per cent. of the population at risk were known to contract the disease. There are many factors concerned with this result, and of these, resistance to infection by the individual is of considerable importance. Immunity may be natural or acquired, and second attacks of typhoid fever are very rare, but a previous attack of typhoid fever does not protect against paratyphoid fever. Immunity can be acquired by inoculation with vaccines prepared from cultures of enteric bacteria. This measure has proved of immense benefit, particularly in military campaigns.

Typhoid fever is a very serious illness, having a mortality which generally varies from 10 to 20 per cent. Paratyphoid fever is milder, shorter in duration and much less fatal, the mortality being of the order of 1 to 5 per cent. Enteric fever attacks all races and ages and occurs

at all seasons of the year, but in this country the incidence of typhoid fever is highest in the autumn and hence it was at one time known as "autumnal fever."

After entry by the mouth the bacteria invade the blood stream and are thus carried to all parts of the body (bacteræmia), but a variable period of time elapses before symptoms appear. This incubation period is seldom less than one week or more than three weeks, and is usually ten to fourteen days. Exceptionally long incubation periods are sometimes recorded, but these may be ambulatory cases suffering relapse. In some outbreaks, however, sickness of short duration, with or without diarrhoea, precedes enteric fever and occurs within a day or so of ingestion of the infected food or water. The patients of such temporary mild illness do not necessarily develop enteric fever, but the occurrence has much epidemiological importance. In every outbreak of enteric fever careful investigation should be made for cases of vomiting, diarrhoea or "gastro-enteritis" occurring about two weeks previously, since the date thereof will approximate the date of the enteric infection and assist in the discovery of the cause. Also, in every outbreak of "gastro-enteritis" the possibility of subsequent enteric fever should be kept in mind. It was recorded in the Croydon epidemic, for example, that a number of cases of vomiting and diarrhoea occurred some two to three weeks before notification of the first cases of typhoid fever.

Although paratyphoid fever may start with an acute gastro-enteritis, the onset of enteric fever is usually gradual and the date thus difficult to decide. The early symptoms of typhoid fever are vague and varied, but common complaints are headache, lassitude, loss of appetite, nausea, constipation or diarrhoea, insomnia, sore throat, bronchitis, pains in the abdomen or back, nose-bleeding, shivering and increasing fever. There is progressive increase in severity of symptoms during the second and third week, after which improvement may set in, but the period of convalescence is usually long. Enteric fever should be considered in any case of unexplained fever, and resort made, within a week, to laboratory aids to diagnosis. Bacteriological examination of blood, faeces and urine should be made and the isolation of the specific bacteria clinches the diagnosis. The Widal reaction is of later and less diagnostic value than blood culture. Early diagnosis is of the utmost importance and laboratory culture of the infecting bacteria from the blood or faeces is often successful in the first week of symptoms, or even occasionally during the incubation period. Cases have been recorded, the so-called *paradoxical carriers*, in which typhoid bacteria were isolated from the faeces weeks before the onset of clinical typhoid fever.

In spite of the great decline in the prevalence of typhoid fever in this country during the past fifty years, no relaxation of thought and effort in the protection of water supplies is permissible if the position is to be maintained and improved.

The Bournemouth and Croydon outbreaks emphasised this fact, and since the latter was considered to be directly water-borne, review of the circumstances will be of interest and value.

The Croydon Typhoid Outbreak, 1937. The Addington Well, from which the implicated supply was obtained, had been in use for forty-nine years without previous epidemiological incident. It is 205 feet deep with upper and lower adits at 150 and 162 feet respectively below engine room floor level, the whole being in the Upper Chalk formation. The latter is practically uncovered in the material area and at least one "swallow-hole," two miles distant, and used as a soakaway for roof, yard and road surface washings, had connection with fissures discharging water into the well or adits. Few habitations exist over the area described as the gathering ground, but at two farms there were potential sources of pollution. In addition, a latrine dug in the Chalk and situated directly over an adit of the well had been in use some weeks prior to the typhoid outbreak by workmen temporarily engaged at an institution adjoining the pumping station.

The yield of the Addington Well is limited to an average of 1·5 million gallons daily, and this suffices for the supply of only a small part of the Croydon Borough, viz., a high level area of approximately 40,000 population, served *via* a storage reservoir of five million gallons capacity. This service reservoir was covered, but had defects in the roof ventilators, which were flush with the ground surface, and the site, utilised as a tea garden, was much frequented by the public in the summer months.

At most times the well yields a clear and bright, hard, Chalk water of satisfactory organic and bacterial purity. On rare occasions, however, *i.e.*, after heavy rainfall (particularly in the winter months when the ground water level is high) slight turbidity, due to the presence of finely-divided mineral matter (clay and chalk) appears together with bacterial impurity. Agar plate counts then increase from 1 or 2 to several hundreds per millilitre, and *Bact. coli* from 0 to several hundreds per 100 ml. On this account, rapid pressure sand filters, operated without coagulants, had been installed, and sufficed for the clarification, but not the bacterial purification, of the water. Chlorination of the filtered water was intermittently applied in doses of less than 0·1 part per million to correct the bacterial condition. The plant was set to work when unsatisfactory analyses were obtained (samples being collected at monthly intervals) and shut down as soon as the next favourable report was received. A bacteriologist was not employed, but "coli tests" were made by the analyst.

On September 24th, 1937, work started in one of the adits and continued for just over a month. Until October 15th the well water was pumped to waste during the day whilst the men were at work, and to the service reservoir at night. From October 16th onwards, however, water was pumped to the reservoir as required, whether work was in progress underground or not. During the whole of this time the water was neither filtered nor chlorinated. Open buckets, periodically removed in a skip of chalk, were used in the adit for micturition, but defaecation underground was denied.

One of the fourteen workmen employed in the adit, first on September 28th, 29th and 30th, and subsequently on nineteen days between October 2nd and October 26th, had suffered from typhoid fever during the 1914-18 war and was, unknown to himself, a chronic *carrier*. Profuse typhoid cultures were consistently obtained from the faeces, but repeated examination of the urine gave negative results.

Filtration and chlorination of the well water were resumed on November 1st, but the well was closed three days later.

On October 27th¹ a case of typhoid fever was notified in the High

¹ A case of typhoid fever notified seven days previously was considered to have no connection with the subsequent outbreak, the patient having been abroad at the material time.

Level area of supply, the date of onset of the symptoms being October 14th. Allowing an incubation period of fourteen days, the date of infection would be at the end of September. There followed 341 cases of typhoid fever (including nineteen secondary cases), the curve, showing dates of onset of symptoms, rising to a peak on November 13th to 18th, and thereafter falling, indicating highest infectivity of the water at the end of October. The water entered the reservoir at the top and was drawn off very near the bottom on the opposite side, hence a lag period of two or three days would be expected. It would seem that there were repeated infections of the water throughout the month that work in the adit was in progress rather than a single instance. There may, however, have been one gross infection of the water at the end of September, the lateness and spread-over of the cases being due to the hold-up in the reservoir. In subsequent experiments we found that cultivated typhoid bacteria remained viable in unchlorinated Croydon water for about four weeks at 10° to 15° C.

Of the population at risk approximately 0·7 per cent. contracted the disease, and there were forty-three deaths (12·6 per cent.). The distribution of cases was very irregular, and in a residential boys' school situated near the reservoir seventeen cases occurred among 150 boys (10·3 per cent.). On the other hand, it is extraordinary that there was only one case, late in December, among over 1,000 occupants (non-immunised) of a mental hospital deriving its water supply direct from the Addington Well instead of from the service reservoir.

In the Ministry of Health Report (1938) on the Inquiry into this outbreak, the following conclusions were expressed: "The epidemic arose from an avoidable and external cause and not from anything in the well itself. In fact the infection was due to an unfortunate and rare coincidence of three factors: (a) constructive changes taking place in the well; (b) one of the workmen being a typhoid carrier; and (c) the process of chlorination being in abeyance."

In subsequent legal proceedings Mr. Justice Stable held that the cause of the outbreak was either a *carrier* or some unidentified, and probably transitory, condition in the gathering ground, with the probability greatly in favour of the former hypothesis.

As in most typhoid outbreaks, the evidence inculcating the water supply was circumstantial, for, in spite of much effort, typhoid bacteria were not isolated from numerous samples of the water, the deposit in the reservoir, or the chalk removed from the adit of the well in the course of the work carried out therein. The investigations did not, however, commence until November 3rd when, as later evidence indicated, the water had ceased to be infective.

Accepting that the epidemic was water-borne, there is no certainty as to the source of the typhoid bacteria, the conclusion that the *carrier* working in the well was the source being based on probability. In support of this probability it was subsequently reported that the typhoid bacteria isolated from a number of the victims of the epidemic all belonged to the same phage-type (D) as the typhoid bacteria excreted by the *carrier* who worked in the well. Typhoid bacteria can be divided by phage-typing into at least six main groups.

The important points indicating that the epidemic was water-borne were that the cases were substantially confined to the high level area of the town which was supplied by the Addington Well, that no other common article of food or drink was found or had a similar distribution, and the outbreak subsided when the water supply was changed. Also, the precautions taken in respect of the workmen engaged in the well were lax, and the water, known to be intermittently polluted, was supplied to the consumers untreated.*

The points leading to the conclusion reached that the infection of the water most probably arose from a workman employed in the well were that the man in question had previously suffered from typhoid fever, he proved to be a *carrier*, consistently excreting large numbers of typhoid bacteria in the faeces, he worked in the well at times which coincided with the onset and course of the epidemic (making allowance for normal incubation periods), and he admitted the use of the bucket for urination whilst at work in the well. Furthermore, the typhoid bacteria isolated from the *carrier* and the patients of the epidemic were of the same phage-type.

Against this view were the strong denials of all the men concerned that defaecation ever took place in the well or adits, and though urination into an open bucket was freely admitted, typhoid bacteria were never found in the urine of the *carrier*. On the former matter Mr. H. L. Murphy, K.C., who held the Ministry Inquiry, stated in his Report: "I am satisfied that the men were warned that if their bowels were moved they should come to the surface where there was adequate lavatory accommodation. I am also satisfied that in this long dark gallery (the adit) where water was flowing there were ample opportunities, if a man were so inclined, for the deposit of faeces, and that there can have been no desire to multiply the daily journeys, up and down, in the skip." With regard to the second point, excretion of typhoid bacteria in the urine may occur intermittently and long periods elapse when negative findings are obtained.

Also, it is possible that there may have been a transient infection of another workman in the well, with temporary excretion of typhoid bacteria in the urine and recovery without clinical signs of the disease, or bacteriological evidence, apart from a positive Widal reaction, when examined in November.

Since it was definitely established that a typhoid *carrier* worked in the well at the material times, it might seem idle to seek another source of infection of the water, but there were other possibilities which can by no means be ignored.

In the first place, it is remarkable, if infection of the water took place in the well, that more cases of typhoid fever did not occur among the population of the mental hospital supplied direct from the well. On the contrary, the epidemic was substantially confined to the high level area served by the Addington reservoir, and the incidence was relatively very high at a boys' school situated close to this reservoir. The distribution would therefore agree with infection of the water in the reservoir, to which routes were available for the access of surface washings and pollution. Since the roof and surrounds of the reservoir were much frequented by the public, the possibilities of specific infection of surface washings were not remote.

With infection of the water taking place in the well, the absence of typhoid fever at the mental hospital could be explained by the following circumstances. There was a certain amount of water storage at the hospital and also a separate pump at the Addington pumping station for the exclusive use of the hospital. If only the main pumps forcing water to the Addington service reservoir were in use following a single instance of specific pollution in the well, the whole of the infected water might have passed to the reservoir. Thus, when the hospital pump later came into use, non-infected water which had freshly entered the well was pumped to the hospital.

Another of the more likely sources of the infection was the latrine dug in the chalk over the line of an adit within 100 yards of the well. This latrine was in use during the summer months preceding the outbreak, and since the chalk at the site was proved not to be compact,

disturbance of the well water having taken place when a borehole was sunk, the possibility of pollution reaching the underground water from the latrine was also not remote. In addition there were other more distant but possible sources of pollution on the "gathering grounds" of the well.

Therefore, although it is probable that the *carrier* working in the well was the source of the infection, other possibilities must be recognised, the manner in which the bacteria passed from the *carrier* to the well water remaining a matter of conjecture.

Avoidable errors in waterworks practice revealed by this outbreak can be divided into those pertaining to normal working, and those relating to special circumstances, such as constructive changes in the well.

In respect of the former, and arising from the absence of competent technical, laboratory and bacteriological help and guidance, there were (a) a lack of recognition of the potential dangers to the source, (b) defective maintenance of works, and (c) inefficient application and supervision of treatment of the water. Intermittent chlorination according to the results of monthly samples was ill-advised and hazardous, even had the chlorine dose been sufficient, since much harm might have arisen in the intervening periods. The removal of all avoidable pollution from the gathering ground, continuous, efficient filtration and chlorination, with regular, competent laboratory control, followed by careful protection of the treated water in the service reservoir and mains, were needed to ensure a safe supply. These changes were indeed all promptly put into effect.

In the second respect, the most important errors were (a) the failure to exclude the well from service whilst work was in progress, or, alternatively, to ensure the safety of the water by efficient treatment, confirmed by close laboratory observations (b) the employment of workmen without medical examination, careful selection, and thorough instruction as to cleanliness, changing of footwear, etc., (c) the use of open buckets for urination.

Wherever possible, it is advisable to close a well while work therein is in progress, and when it is completed the water should be pumped to waste until samples have been proved normal and satisfactory. If closure is impossible, special care must be given to treatment and laboratory examinations of the water.

Whilst medical examination of workmen should not be ignored, more reliance should be placed on efficient and carefully controlled treatment of the water. In spite of all other circumstances, the Croydon typhoid outbreak would have been avoided had the water been efficiently chlorinated, i.e., by such a dose of chlorine that an excess of not less than 0.1 part per million remained in the water in the service reservoir (or, otherwise, after a minimum contact of an hour).

Although circumstances were abnormal and their concatenation exceptional, the suspension of treatment, and particularly of chlorination, was the most serious omission. It was not common practice at that time for men employed on waterworks to be medically examined nor unusual for buckets to be used for urination.

Much good, both to Croydon and the waterworks industry in general, has resulted from the unfortunate experience of this typhoid outbreak. The Corporation of Croydon can now claim to possess one of the most competently organised and managed municipal waterworks undertakings in the country, and, following the issue by the Ministry of Health of information and recommendations in such pamphlets as Circular 1684 (1938) and Memo. 221 (1939), there has been wider understanding of the dangers to which water supplies are exposed, and of the measures necessary for their protection. These pamphlets are quoted in the Appendix of this volume, and they should be carefully studied by all interested in public water supplies.

The medical examination of waterworks personnel is primarily directed to the discovery of enteric *carriers*. It should include inquiries as to any history of previous enteric illness, bacteriological examination of fæces and urine, together with blood serological tests. The Widal reaction is helpful as a sorting-out test when large numbers of men have to be examined, but it is unreliable and gives positive results in immunised persons. The Vi-antibody reaction of Felix, although not yet fully investigated, appears to be capable of detecting the *carrier* with almost complete certainty. The excreter of enteric bacteria is, however, proved by the detection of the specific bacteria in the urine or fæces.¹ When there is any question of doubt, at least three consecutive bacteriological examinations of properly collected specimens of urine and fæces should be made at intervals of a few days.

In spite of every possible care in protection of sources and selection of workmen, including medical examination, safety is by no means assured, and greater reliance should be placed on a competently designed and effectively operated system of treatment of the water.

The importance of the purification of water supplies in the prevention of enteric fever, cholera and dysentery has been abundantly proven by experience in this country since 1855, when, by Act of Parliament, filtration of the river-derived supplies to London became compulsory, and led to gradual extension of the practice outside the Metropolis. The annual death-rate from enteric fever, per million of the population, has progressively declined in England from an average of 371 in the 1871-75 period to 47 in 1914 and 4.6 in the 1934-38 period.

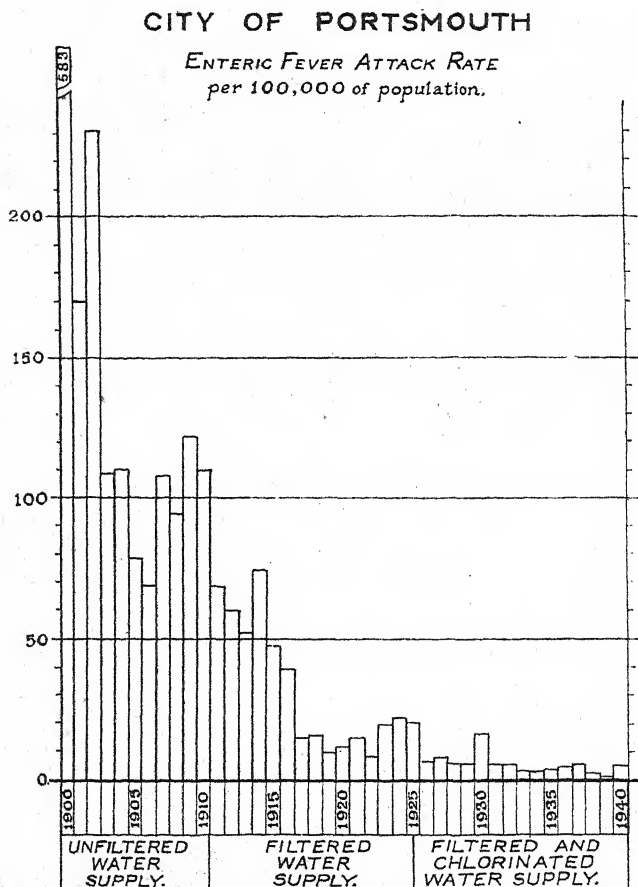
As an example of this decline, there is shown in the Chart on p. 586 the notifications of enteric fever in the City of Portsmouth during a period of forty years, together with the changes which have taken place in the treatment of the public water supply. The fall in the prevalence of enteric fever is, of course, due to many factors, one of which is improvement in the purity of water supplies.

Experience in the U.S.A. has been similar, and, coincident with the expansion of water purification, the typhoid death-rate, per million, of seventy-eight cities having a combined population of 22½ millions in

¹ In a very rare form of *carrier*, the typhoid bacteria are enclosed (e.g., in a bone) and are not excreted in the fæces or urine, but should an abscess form, the discharged pus will contain typhoid bacteria.

1910 and 37 millions in 1938, has fallen progressively from an average of 150.4 in the 1910-14 period to 9.4 in the 1934-38 period.

The general relation of water supply to the incidence of typhoid has been summarised by Dr. S. J. Crumbine (1927) of the United States Public Health Service—"Before the days of modern water filtration, typhoid fever was held to be chiefly a water-borne disease. During the past few years, the epidemiological picture of typhoid fever has been greatly changed. Instead of being a disease distributed chiefly by water



supplies and, therefore, attacking the urban section of our population, epidemiological studies reveal the fact that the rural and small town populations are more often affected and that explosive epidemics are now more often milk-borne than water-borne in origin. Contact infections and the contamination of food by infective house-flies also play an important rôle in the dissemination of the disease, this type of dissemination being the chief sources of the sporadic or endemic type of cases."

Bacterial Dysentery. The bacteria responsible for this disease have already been described (see p. 531). The disease, though not rare, is less common in this country than abroad, particularly the tropics. Water plays, however, a comparatively unimportant part in its spread, food and flies now being more important, but water-borne outbreaks are possible. The general principles involved in the protection of water supplies from contamination by dysentery bacteria are similar to those in respect of enteric bacteria. Dysentery *carriers* occur and are discovered by the bacteriological examination of the faeces, blood tests being of little value.

The disease is more prevalent where personal hygiene is lax, as in mental hospitals, and in war-time when large numbers of men are in close association and efficient sanitation is difficult.

Bacillary dysentery is characterised by diarrhoea and the passage of blood and mucus in the stools. There is usually abdominal pain, and headache, but fever is variable and may be absent. Unlike typhoid fever, the incubation period is short and the onset sudden. For bacteriological diagnosis a freshly-collected stool, or swabbing of the rectal mucosa, should be examined, and special laboratory culture media employed, such as desoxycholate-citrate agar.

Cholera. This is essentially a water-borne disease and calamitous outbreaks arise from the infection of water. The most recent outbreak of this kind in Europe occurred at Hamburg in 1892. Although occasional cases have been imported, the disease has not spread in the British Isles since 1873. Prior to that time, serious epidemics occurred, and in 1854, for example, there were no less than 20,000 deaths from cholera in England. London bore a considerable share in these epidemics.

In addition to water, cholera is spread in a lesser way by uncooked vegetables and other foods, the infection being due to faecal contamination derived from a case or *carrier* of the disease. Flies may carry the infection from excrement to food. *Carriers* are usually transient and the condition seldom persists for more than a month or two. Excretion of the vibrios in the faeces may, however, take place before the onset of the disease. The onset is very sudden and the incubation period short, varying from a few hours to a few days.

Cholera is a very serious disease and the case mortality may exceed 50 per cent. It is characterised by severe diarrhoea, vomiting, abdominal and muscular pains, exhaustion and collapse. There is no fever, the temperature being subnormal.

Diagnosis is made on clinical grounds, aided and confirmed by bacteriological examination of the stools. The disappearance of cholera from this country has been brought about by improved sanitation and more careful selection and treatment of water supplies. Vigilance must, however, be constantly maintained to prevent its reappearance.

Other Possible Bacterial Diseases. It is manifestly possible that *Salmonella* bacteria, other than paratyphoid bacteria, may gain access to water, both from human and animal excreta, and cause disease (acute

gastro-enteritis) in man, but, though they have been demonstrated in sewage, water has not yet been implicated in the spread of *Ærtrycke*, Enteritidis or other *Salmonella* infections. Food is the usual vehicle of spread.

Occasionally the consumption of impure water gives rise to undefined illness, with abdominal pain, vomiting and diarrhoea, which cannot be associated with any specific organism. A small outbreak of this nature occurred at Poplar, London, in 1926, where, by a faulty main connection, unpurified instead of fully-treated river water was supplied to the consumers. A similar but much larger outbreak occurred in Surrey in 1936 when a well in the Chalk from which the water supply was derived received pollution from a fractured sewer. In another case of our experience several hundred workers in a factory suffered from gastro-enteritis when, by a cross-connection, crude canal water entered the drinking-water system.

Many diseases have been alleged to have been contracted from the water of swimming baths, but there has probably been some exaggeration in this matter, though swimming in sewage-polluted rivers is dangerous. Sinus and respiratory infections, enteric fever, skin diseases, Weil's disease and some of the infections of childhood could possibly be transmitted by swimming-bath water, but it is fairly generally agreed that direct contact, or "droplet infection," associated with lowered vitality of the bathers due to prolonged immersion, are more probable causes than transmission by the water itself.

The rapidly extending practice of treating swimming-pool waters by continuous circulating purification, with the maintenance of a decided residual of free chlorine, is designed to protect bathers from the risk of water-borne infections and cross-infections. These measures, properly applied, give reasonable safeguard against bacterial and leptospiral infections, but their efficiency against viruses has not been established.

Amœbic Dysentery.

This disease does not occur in this country but it is common in Africa, India, other tropical countries and in America. It is caused by an amœba, known as *Entamœba histolytica*, and the infection is derived from contaminated food or water. The amœbæ are excreted in the fæces of cases and *carriers* of the disease (*carriers* being very important), and flies may convey the infection to food. The disease may be acute or chronic, and is characterised by diarrhoea with the passage of blood and mucus in the stools, emaciation and the development of liver abscesses.

The amœbæ do not survive for long in sewage, water, etc., but they form cysts which are resistant and chiefly responsible for the spread of the disease. In laboratory experiments, Chang and Fair (1941) found that the cysts survive in water for nearly three months at freezing temperatures, about a month at 10° C., about ten days at 20° C. and three days at 30° C. The cysts were found to be more resistant than

coliform bacteria to chlorination, but the concentration of gaseous chlorine needed to destroy them was well within the range of practical superchlorination, provided that the contact period can be extended to thirty minutes or longer. The experiments indicated that at ordinary working temperatures a margin of safety would be obtained by chlorination at 5 parts per million and contact time of one hour, provided a residual chlorine reaction of at least 1 part per million remained.

Leptospiral Jaundice (Weil's Disease).

As indicated on p. 517, this disease is caused by *Leptospira icterohæmorrhagiæ*, a spirochæte sometimes present in excrementally contaminated water, mud and slime, and capable of penetrating the skin. To become infected, therefore, it is not necessary to drink contaminated water and most cases appear rather to arise from wading or bathing. The typical symptoms are sudden shivering and headache, with fever and collapse, followed in a few days by jaundice and often hæmorrhages. Despite the title of the disease, jaundice is not always present. The clinical diagnosis may be confirmed by early examination of the blood for leptospiræ, but it is usually necessary to resort to animal inoculation. The organism appears in the urine towards the end of the second week, at which time also, the patient's serum develops agglutinins for *L. icterohæmorrhagiæ* and the Adhesion Test (see p. 519), becomes positive.

Diseases Due to Viruses.

Viruses are responsible for many human diseases such as influenza, small-pox and poliomyelitis. Animal diseases, such as psittacosis, foot and mouth disease and rabies, are also due to viruses and may be transmitted from animals to man.

In both man and animals, the viruses are present in the excreta of cases and *carriers*, but little is known as to their distribution and viability. Recent investigations of the viruses of acute poliomyelitis have, however, given some information on this subject.

Acute poliomyelitis (infantile paralysis) is a serious disease fairly common in this country and characterised by fever and paralysis. The latter often becomes permanent, with crippling effects. Although children are mostly attacked, adults are not immune. It is considered that the infection is mostly "droplet" spread and enters the body by the nasopharynx, the respiratory tract playing a more important part than the alimentary tract. This view is open to doubt, and the methods of spread and infection are still obscure.

The viruses of poliomyelitis are identified by the injection of the rhesus monkey which is susceptible to the disease. The viruses have been discovered in the urine and fæces of cases and *carriers*, and positive findings in fæces up to three months after an attack have been reported. The viruses are also found in the sewage of towns where the disease is present among the inhabitants and they disappear after the outbreak has subsided. Theoretically it is possible for poliomyelitis to be con-

tracted from sewage-polluted water supplies or swimming bath waters. Similarly, other virus diseases could be derived from excremental pollution of animal origin. No evidence has yet been obtained that water supplies or swimming baths play any part in the spread of poliomyelitis, but, with the present lack of knowledge, an open mind should be kept. Infection *via* the mouth and alimentary tract is a possibility, and, in fact, would better accord with some of the circumstances than infection by inhalation. The viruses are filter-passers, and it has been reported that a poliomyelitis virus was found, in laboratory experiments, not to be inactivated by chlorine in a concentration of 0.5 part per million and a contact time of one-and-a-half hours (Kempf and Soule, 1940).

Epidemic infective hepatitis (catarrhal jaundice)—probably a virus disease—is fairly prevalent, and at least two outbreaks, for the spread of which polluted water was held responsible, have been recorded (*Brit. Med. Jour.*, November 27th, 1943).

Insects, etc.

Samples collected from mains, reservoirs and swimming baths are often sent for examination on account of the presence in the water of visible life, which might, it is thought, cause illness in the consumers, or be injurious to bathers. Forms of life commonly found in such samples are Cyclops, Daphnia, Gammarus pulex, Asellus aquaticus, Anguillulæ, Nais and the larvæ of mosquitoes and midges, such as the blood-worm or larva of Chironomus plumosus. There is no evidence that any of these low forms of life cause disease in this country, but they are of significance for other reasons, and their presence is objectionable.

Diseases due to Helminths

A number of worms and flukes are parasitic to man, and, in many cases, they inhabit the intestines. Ova and larvæ are passed out in the fæces, whence they may gain access to water and spread the infection. This problem is a minor one in Great Britain, but it is of considerable importance in many parts of the world. Parasitic worms commonly found in Great Britain are the three round worms, *Oxyuris vermicularis* (threadworm), *Trichuris trichiura* (whipworm), *Ascaris lumbricoides*, and the flat worm, *Tænia saginata*.

(A) **Nematodes. Round Worms.** 1. *Oxyuris vermicularis* lives in the colon and rectum, and the fæces of infected persons contain large numbers of worms and ova. The male worm measures about 4 mm. in length and the female about 10 mm. These worms are most often found in children, and cause much irritation of the anus.

2. *Trichuris trichiura* also inhabits the large intestine and is larger than *oxyuris*, measuring 4 to 5 cm. in length, the female being somewhat longer than the male. The anterior three-fifths of the worm is very thin in relation to the posterior portion, hence the name whipworm. It is a very common worm, and the ova are passed out in the fæces of infected persons. Symptoms are usually slight and often absent.

3. *Ascaris lumbricoides* is a much larger round worm, measuring

7 to 12 inches in length in the female and 4 to 8 inches in the male. It inhabits the small intestine, but may migrate to other parts of the body and cause serious trouble. The ova, which have a very thick covering, are found in the fæces.

4. Ankylostomiasis or hookworm disease is common in tropical countries, and occurs amongst miners in Europe. A small outbreak was recorded in Cornwall but it did not extend. The disease is due to infection of the small intestine by nematodes, of which there are two common species, *Ankylostoma duodenale* and *Necator americanus*. They cause severe anæmia. The ankylostomes are small cylindrical worms $\frac{1}{4}$ to $\frac{1}{2}$ inch in length, and are blood-sucking parasites. The eggs are discharged in the fæces of the infected person, and develop, where conditions of warmth and moisture are favourable, into free swimming and climbing larvæ which make for water. In this stage it infects man usually through the skin, but occasionally by the mouth, if infected water or vegetables are consumed.

Prophylaxis consists, therefore, in preventing fæcal contamination of the soil, of water and of foodstuffs, such as vegetables, which are consumed in the uncooked condition.

5. Dracontiasis or Guinea-worm disease occurs in Africa, India and other tropical parts. The disease is caused by a worm and is acquired by drinking water containing the embryos. These develop in the human body, the female to a large size, but the adult male does not exceed 1 inch in length. The female, after impregnation, penetrates the intestines and migrates to the subcutaneous tissues, where it attains its full development and may be 1 foot to 3 feet in length. When mature almost the whole of the worm is occupied by the uterus, which is full of coiled-up embryos. Finally she bores through the skin, often at the foot or ankle, to discharge the embryos into water. Having found water the embryos seek an intermediate host which is generally a cyclops. The larvæ can survive for six days in clear water and for two or three weeks in muddy water, which gives them plenty of time to gain entry to the intermediate hosts, e.g., cyclops.

When the cyclops die the guinea-worm larvæ also die, but, if the cyclops are swallowed by man in drinking water, they are digested by the gastric juice and the worm embryos liberated, when they develop as previously described.

Prophylaxis consists in preventing infected persons from coming into contact with water supplies, and in the destruction of the intermediate hosts. In infected areas, water used for drinking purposes should be thoroughly purified or boiled. Cyclops are killed by heating to 65° C. Careful filtration will remove cyclops and excess lime will kill them, but they are resistant to heavy doses of chlorine.

(B) Flat Worms. (1) Cestodes. Tapeworms. The commonest types of tapeworms are *Tænia solium* (pork tapeworm), common in Germany but exceedingly rare in Great Britain, *Tænia saginata* (beef tapeworm), the common type in England, *Tænia echinococcus*, not natural to Great Britain but common in Australia and elsewhere.

Tænia solium attains a length of about 12 feet, and *Tænia saginata* 20 or more feet.

In their adult form they inhabit the intestines of man. The worms consist of a minute head with suckers, a neck, and many segments which contain both male and female organs. The mature segments containing many ova are shed and discharged in the fæces.

The eggs for further development must, in the case of *Tænia solium*, be ingested by man or pig, where, in the stomach, the egg shells are digested and the embryos liberated to develop in various parts of the body, such as the muscles, liver and brain, into cysticerci. This may be a very serious disease in man, and pork so affected is described as "measled."

The larval or cysticercal stage of *Tænia saginata* is passed in cattle, and not in man.

Polluted water plays some part in the propagation of these diseases, though it is probably only a very minor one, except indirectly through the medium of uncooked vegetables, such as celery, watercress, etc.

Tænia saginata can only be propagated to cattle by infected water, since man cannot act as the intermediate host in this case. It is contracted by eating infected beef.

The third tapeworm, *Tænia echinococcus*, is of considerable importance in Australia, the Argentine and elsewhere, but does not occur naturally in England. The adult worm inhabits the intestines of dogs, but the larval stage may be passed in sheep, cattle or man, giving rise to hydatid or cystic disease. *Tænia echinococcus* is a small worm only 4 to 5 mm. in length, consisting of a head and two or three segments. The eggs are discharged in the fæces, and man may become infected by personal contact with affected dogs, or by eating food or drinking water contaminated by the excreta of dogs.

(2) **Distomiasis.** The flukes or trematoda are parasitic platyhelminths, usually with leaf-shaped bodies, which may infest the liver, lungs, intestines and blood-vessels of man.

Fluke disease in man occurs in Africa, India, China, South America, etc., but only imported cases are seen in Great Britain, though liver flukes are not uncommon in ruminants. The ova of the flukes are found in the fæces, and thus the disease is spread by the contamination of water, soil, grass, etc., with the infected material.

Schistosomiasis or bilharziasis is a very common disease in Egypt, other parts of Africa and Asia, and is due to the blood flukes of which three species infect man, *Schistosoma hæmatobium* (Egypt), *Schistosoma mansoni* (S. America), and *Schistosoma japonicum*. The first two species infect man only, but the last also attacks domestic animals.

The flukes are peculiar in that the sexes are separate, but the life histories are similar in each case.

Schistosoma hæmatobium inhabits the portal vein and its branches, chiefly the veins of the bladder and rectum. The passage of blood in the urine and stools, and anæmia, are common symptoms. The adult

male is a small white worm about $\frac{1}{2}$ inch in length, whilst the female is considerably larger and finer.

The eggs are oval in shape (0.15 mm. \times 0.06 mm.) and one end has a terminal spine. They are excreted in the urine and rarely in the fæces.

Schistosoma mansoni chiefly inhabits the portal and mesenteric veins, and the eggs, which are usually passed in the fæces of the infected person and rarely in the urine, have a lateral spine.

An important stage in the life history of these worms is passed in water. The eggs reach water by pollution with urine or fæces, and hatch out into free swimming larvæ (the miracidium), which die after twenty-four hours unless they reach a suitable host. The intermediate host in this case is a fresh water snail in the body of which the larva becomes a sporocyst which gives off many daughter sporocysts. These produce large numbers of cercariæ which leave the snail and swim about in the water.

The cercariæ are bifid-tailed organisms just visible in clear water to the naked eye, and resembling minute white hairs. After forty-eight hours in water the cercariæ die unless they gain access to the human body.

Access is obtained by piercing the skin, or the mucous membrane of the mouth if the water is swallowed. They then enter the blood stream, are carried to the liver and portal veins, and develop into adult male and female worms in about two months, and the cycle is thus completed. External contact with water containing cercariæ, as in washing, wading and swimming, is the commonest mode of infection.

The methods employed for the prevention and eradication of this disease are :—

1. Treatment of the infected persons.
2. Prevention of pollution of water by human excreta.
3. Destruction of snails in watercourses and reservoirs.
4. Treatment of water and destruction of cercariæ.

The snails can be removed mechanically from water. They are susceptible to drying and are killed by copper sulphate (5 parts per million).

Since the cercariæ perish after about two days in water, storage is an effective method of treatment. They are not completely removed by coagulants and sand filtration, nor are they destroyed by chlorine in the doses usually employed in waterworks practice (up to 2 parts per million). There is evidence that cercariæ are killed by the excess-lime treatment of water.

In countries where bilharziasis occurs, reservoirs should be kept clear of snails, the water should be carefully purified, and an interval of at least forty-eight hours should intervene, by storage in closed reservoirs, before the water reaches the consumers. By such means danger of spreading the disease by the water supply is avoided.

Small quantities of water can be rendered safe by boiling. Water that is required for washing or bathing purposes only can be effectively treated by cresol (1 in 10,000).

References

- AINSWORTH. 1933. *Brit. Dent. J.*, 55, 233.
BLACK and MCKAY. 1916. *Dent. Cosmos*, 58, 129, 477, 627, 781, 894.
BOISSEVAN. 1933. *Colorado Medicine*, April.
BROMEHEAD. 1941. *Lancet*, 1, 673.
CHANG and FAIR. 1941. *J. Amer. Wat. Wks. Assoc.*, 33, 10.
CHURCHILL. 1931. *Indust. Eng. Chem.*, 23, 996.
CRUMBINE. 1927. *Manual of Amer. Wat. Wks. Assoc.*, 1941.
DEAN. 1933. *J. Amer. Dent. Assoc.*, 20, 319.
DEAN. 1935. *Amer. Pub. Hlth. Reports*, 50, 206.
DEAN and MCKAY. 1939. *Amer. J. Pub. Hlth.*, 29, 590.
DONALDSON. 1936. *An. Rep. of the School Dent. Off. for Essex*.
EAGER. 1901. *Amer. Pub. Hlth. Reports*, 16, 44.
HART, PHILLIPS and BOHSTEDT. 1934. *Amer. J. Pub. Hlth.*, 24, 936.
KEMPF and SOULE. 1940. *Proc. Soc. exp. Biol., N.Y.*, 44, 431.
MAHER. 1939. *U.S. Geol. Survey, Geol. Pamph. No. 1*.
MINISTRY OF HEALTH. 1938. *Report on a Public Inquiry into an Outbreak of Typhoid Fever at Croydon*, H.M. Stationery Office.
SMITH, LANTZ and SMITH. 1931. *Tech. Bull. No. 32*, Univ. Arizona.
SCOTT, KIMBERLEY *et al.* 1937. *J. Amer. Wat. Wks. Assoc.*, 29, 9.
VELU. 1939. *C.R. Soc. Biol.*, 108, 377, 635, 750.
WILSON. 1939. *Nature*, 144, 155.
WILSON. 1941. *Lancet*, 1, 211, 375.

CHAPTER XXXVII

STANDARDS AND STANDARDISATION IN WATER EXAMINATIONS

WATER authorities are under statutory obligation to supply wholesome water, which means that when consumed it shall cause no ill-effects. The consumers, however, demand more than that, and generally require water which is attractive in appearance, reasonably cool, palatable and not too hard. Variations to an extreme degree occur in the water supplies in different parts of the country. For example, highly coloured waters containing traces of suspended matter, often plumbo-solvent, and of dubious bacterial purity, are acceptable in some areas because they are soft, but in other districts where the consumers are accustomed to bright and colourless waters, such supplies would be regarded as dirty or polluted. The variations in hardness of public water supplies range roughly from 2 to 50 parts per 100,000, but the majority of both domestic and industrial consumers prefer soft waters. In a few hard-water areas, the water authority is under statutory obligation to soften, and a commonly prescribed limiting hardness is 14 parts per 100,000. Apart from such exceptions, and the general obligation of wholesomeness, no standards have been prescribed in this country.

Analytical and bacteriological standards would necessarily have to be elastic and carefully considered in relation to other circumstances, but guiding standards for the limitation of impurity (physical, chemical and biological) would be helpful and would stimulate progress. Standardisation of laboratory technique in water examinations, whilst leaving scope for individuality and research, is also required. Similarly, more uniformity in the expression of results, and a greater understanding of their significance and limitations, are necessary to avoid much of the confusion and wasted effort which still occur. A beginning has been made in this direction in respect of the bacteriology of water, in the issue, by the Ministry of Health, of Report No. 71, "The Bacteriological Examination of Water Supplies," published by His Majesty's Stationery Office. The objects of this Report are stated to be :—(1) to provide a description of technique the adoption of which will ensure sufficient uniformity in the practice of bacteriological examination of water to permit of comparison of the results obtained in different laboratories; (2) to explain to sanitary inspectors and others the precautions necessary in obtaining and transmitting samples to the laboratory; (3) to assist in assessing the results of bacteriological examination in terms of hygienic quality.

The Report substantially succeeds in these objects and doubtless the procedure of periodical revision will be continued. It is a valuable guide and help to bacteriologists, analysts, medical officers of health,

sanitary inspectors and engineers interested in water supplies, to all of whom its careful study is strongly recommended. The closest attention must be given to detail in the selection of sampling points, the collection of bacteriological samples and their examination, for in these matters there is still much need for improvement. Also, there is a tendency, in spite of due warning, to adhere to the proposed limiting standards of bacterial impurity too rigidly and without proper regard to topographical and other circumstances affecting the samples. It cannot be too often emphasised that judgment on a water supply cannot be passed solely on the bacteriological examination of a sample and still less so on the presumptive coliform reaction alone.

So far no attempt has been made to obtain standardisation in the chemical examinations of water samples,¹ and there is a growing and regrettable tendency to ignore the value of such analyses. The direct hygienic importance of the bacteriological examination is far greater than that of the chemical analysis, but the latter should by no means be neglected. It may have direct or indirect hygienic importance and has also the following uses :—

1. To confirm the satisfactory physical characters of the water.
2. To establish the absence of excess of saline, metallic or other constituent, or of plumbo-solvent and corrosive properties.
3. To disclose changes in the character of a supply according to climatic conditions.
4. To assess the suitability of a water for treatment. It is important when chlorination is under consideration to know the chemical analyses of a water.
5. To verify the efficacy of treatment processes.
6. Chemical analyses are essential when industrial uses of water are under consideration.

In the U.S.A., "Standard Methods for the Examination of Water and Sewage," dealing with both chemical and bacteriological examinations of drinking waters, industrial waters, swimming-bath waters and sewage, has been issued since 1905. It is a comprehensive, authoritative and most valuable work, prepared, approved and published jointly by the American Public Health Association and the American Water Works Association, is now in its eighth edition—fifth printing (1941)—and a further revision is contemplated. It is an example which could well be followed in this country.

The procedure of sampling, the technique of laboratory examinations and the expression of results are carefully described, standardised, and modified at each revision according to experience and research. The standards prescribed are generally acceptable and attainable without undue difficulty. Although latitude is allowed in their application, the standards are not intended to be the highest which water authorities should strive to achieve, but as the lowest allowable with reasonable safety, *i.e.*, they are the maximum limits of permissible impurity.

¹ A Report, "Methods of Chemical Analysis as Applied to Sewage and Sewage Effluents," has been issued by the Ministry of Health (see Chapter XIX).

The information contained in the following remarks is derived from the above-mentioned "Standard Methods" and from "Water Works Practice" (1941), the manual of the American Water Works Association.

Although the standards are only official in their application to drinking water supplied to the public by common carriers in inter-state commerce (trains and steamships), they have become generally accepted for reference to municipal and private water supplies.

1. **Source and Protection.** The water supply shall be :—

- (a) Obtained from a source free from pollution ; or
- (b) Obtained from a source adequately protected by natural agencies from the effects of pollution ; or
- (c) Adequately protected by artificial treatment.

The water supply system, including reservoirs, pipe-lines, pumping equipment, purification works, distributing reservoirs, mains and service pipes, shall be free from sanitary defects.

2. **Bacteriological Examination.** The bacteriological examination includes :—

- (a) Enumeration of colonies growing on gelatin or agar after forty-eight hours' incubation at 20° C.
- (b) Enumeration of colonies growing on agar after twenty-four hours' incubation at 37° C.

The colonies are counted by the aid of a lens giving a magnification of approximately $2\frac{1}{2}$ diameters and are expressed per ml. of water. The agar plate count in twenty-four hours at 37° C. should not exceed 100 per ml.

- (c) The quantitative estimation of organisms of the *Bact. coli* group by applying specific tests to multiple portions of measured volume.

The Committee included only (c) in the bacteriological standard recommended, believing that (a) and (b) would not add information of sufficient importance to warrant complicating the standard by including them in the required examination. The omission of plate counts from the standard is not to be construed as denying or minimising their importance in routine examinations made in connection with the control of purification processes. On the contrary, the Committee wishes to record its opinion that one or both plate counts are of definite value in such examinations, and to emphasise that it is chiefly in the interest of simplicity that they have been omitted.

The *Bact. coli* examination (c) is, therefore, the only one included and is standardised as follows :—

The standard portion of water for this test shall be 10 ml. The standard sample for this test shall consist of five standard portions of 10 ml. each.

When less pure waters are examined, smaller quantities of water should be tested. Ordinarily not less than three portions of each sample shall be tested, the portions being even decimal multiples or fractions of a millilitre, for example, 10 ml., 1 ml., 0.1 ml., 0.01 ml., etc.

The test includes : (a) primary cultivation in lactose broth incubated twenty-four hours at 37° C. (presumptive test). Presumptive reactions arising only on the second day of incubation are not accepted unless confirmed by (b); (b) sub-cultures on Endo or eosin-methylene-blue plates or the formation of gas within forty-eight hours with incubation at 37° C. in a special liquid medium, such as brilliant-green lactose bile (confirmed test); and (c) investigation of individual colonies (completed test). The colonies are transferred to an agar slope and a lactose broth fermentation tube. The demonstration after incubation for twenty-four hours at 37° C. of Gram-negative non-spore-forming bacilli in the agar culture, and the formation of gas in lactose broth constitutes a completed test, indicating the presence of coli-aerogenes organisms.

Bacteriological Standard. 1. Of all the standard (10 ml.) portions examined, not more than 10 per cent. shall show the presence of coli-aerogenes organisms. This is practically equivalent to a "most probable number" of coliform bacteria of 1 to 2 per 100 ml.

2. Occasionally three or more of the five equal (10 ml.) portions constituting a single standard may show the presence of coli-aerogenes bacteria. This shall not be allowable if it occurs in more than :—

(a) Five per cent. of the standard samples when twenty or more samples have been examined.

(b) One standard sample when less than twenty samples have been examined.

The Bact. coli standard, except for the loopholes of clause (2), is reasonable, and it is to be noticed that it applies to coli-aerogenes bacteria as a whole and not solely to faecal types of Bact. coli.

In our experience, waters in this country derived from good, underground sources, and waters efficiently purified contain no Bact. coli, nor coli-aerogenes bacteria, in 50 ml. of water, and this standard can uniformly be obtained without difficulty. Failure to attain this result in treated waters would be regarded as indicating inadequate purification, and with all final waters it is our custom to examine quantities of at least 100 ml.

3. Physical Characteristics. The water should be clear, colourless, odourless and pleasant to the taste.

Turbidity should generally be under five and should not exceed ten (silica scale). The standard unit of turbidity is considered as that produced by 1 part per million of silica (diatomaceous earth or fuller's earth) in distilled water.

Odour should not be detected in the cold, nor when the water is heated to nearly boiling point.

4. Chemical Characteristics. The water should be free from toxic salts and should not contain an excessive amount of soluble mineral substances, nor of any chemicals employed in treatment.

The results of the chemical analysis are expressed in parts per million, and the following are the suggested limits for various constituents :—

- | | | | |
|---------------------------------------|-----|--------|-----------------------|
| 1. Lead shall be less than | ... | ... | 0.1 parts per million |
| 2. Copper shall be less than | ... | ... | 0.2 " " " |
| 3. Zinc shall be less than | ... | ... | 5.0 " " " |
| 4. Iron shall be less than | ... | ... | 0.3 " " " |
| 5. Sulphate shall be less than | ... | 250.0 | " " " |
| 6. Magnesium shall be less than | ... | 100.0 | " " " |
| 7. Total solids shall be less than | ... | 1000.0 | " " " |
| 8. Chlorides (Cl.) shall be less than | ... | 250.0 | " " " |
9. The water should contain no caustic alkalinity.
 10. The water should contain a residual alkalinity of at least 10 p.p.m. if it has been treated with sulphate of aluminium or other aluminium compound.
 11. The carbonates of sodium and potassium taken together and calculated as normal calcium carbonate should not exceed 50 p.p.m.
 12. The water should have no odour or taste of free chlorine.

It will be noted that as far as laboratory tests are concerned the only standard with regard to the sanitary quality of a water is based on the presence of coli-aerogenes bacteria. No mention is made of ammoniacal nitrogen, albuminoid nitrogen and oxygen absorbed from permanganate, matters which at one time were considered important.

Partial sterilisation by chlorination assumes, therefore, a greater importance than general purification, but we should regard it as a mistake if the latter comes to be unduly neglected in the treatment of impure waters, such as those from rivers. Chlorination is, in our view, to be regarded in such cases as an adjunct to other processes of purification, providing an additional and not the sole line of defence. Just as pasteurisation of milk should not provide an excuse for laxity in the production and handling of milk, so chlorination should not permit the distribution of waters of low grades of organic purity.

The mere presence of organic matter does not, so far as we know, render a water unwholesome, but it is an index of impurity or an expression of imperfect purification. Organic impurity also complicates chlorination and reduces its efficacy and reliability.

For these reasons we consider that standards in respect of organic purity, applying to both raw and final waters, would be advantageous, since such would provide confirmation of effective purification. High figures for the albuminoid nitrogen and oxygen absorbed from permanganate determinations in a final water would, in our view, indicate inadequacies in the purification methods.

An important fact, emphasising the necessity for purification in addition to chlorination, must be considered in connection with water supplies in tropical and other parts, where diseases, caused by protozoa and other forms of life more resistant to chlorine than bacteria, may be disseminated by water.

The American views with regard to the physical and chemical standards are generally acceptable, and the latter are well within the

limits of safety. The recommendation that a treated water shall have no odour or taste of free chlorine appears to imply that the water distributed to the consumers shall not contain residual chlorine. De-chlorination of the water before distribution is often practical, but, under existing conditions in Britain, it is deliberate practice to distribute water containing significant traces of free chlorine or chloramines.

The standards for metallic impurities, such as iron, copper and zinc, are stringent, though not unreasonable, whilst that for lead is advisable, and should not be relaxed.

A standard for manganese appears to have been omitted, but, although the small traces of this metal sometimes contained in water are not harmful to health, its effects as regards discoloration and deposits may be similar to those of iron, and hence a limit similar to that for iron might be suggested.

The limits for total solids and chlorides are, on the whole, reasonable but exceptions must often be made. Many water supplies, obtained from boreholes in England and elsewhere, contain considerably more solids in solution than are here specified, and have been used for drinking purposes for many years with satisfactory results. The chlorides, expressed as sodium chloride, are limited to 412 parts per million, but there are waters having twice to thrice that salinity which have been in use in England for many years without known ill-effect. Such waters would not, however, be approved for public supply purposes if others were available, or removal of chlorides were practicable.

A limiting standard for magnesium and sulphates is recommended, but the general question of the "hardness" of water is left uncertain and exceedingly hard waters could comply with the various standards.

It appears that the presence of lead, copper or zinc in excess of the prescribed limits might lead to the rejection of a supply, but failure in respect of the other chemical standards would not suffice for rejection unless an alternative supply of better quality is readily available.

Although the standards as a whole appear to have given reasonable satisfaction since the 1925 revision, there has recently been considerable demand for further revision. Accordingly, the Surgeon-General of the United States Public Health Service appointed an advisory committee to consider desirable changes in the present text of the Standards.¹

It appears that the following are the main subjects for reconsideration :—

1. **Bacteriological Standards.** No material increase in the stringency of the standard is proposed, but it is suggested that the volumes of water examined for coli-aerogenes bacteria should be increased. Also, the system of averaging results might be modified, the period for averages being limited to one month. A water supply would thus have to meet both requirements of the standard during any one month.

2. **Collection of Samples.** On account of the changes which might take place in a water during passage through the reservoirs, mains, etc.,

¹ For the recommendations of this Committee, see *Jour. Amer. Water Wks. Assoc.*, January, 1943.

it is suggested that the standards should not be applied to samples collected exclusively at the outlet of the waterworks, but the whole series should include a specific minimum number of samples collected routinely from various points in the distribution system.

3. Chemical Standards. Less stringent standards are suggested for copper, zinc, caustic alkalinity, and the carbonates of sodium and potassium. Permissible limits for fluoride, boron and selenium should be prescribed.

4. Raw Water. In view of the breakdown which may occur in over-loaded treatment plants, it has been suggested that limits of impurity should be prescribed for raw waters.

PART VIII

THE PURIFICATION AND TREATMENT OF WATER

CHAPTER XXXVIII

PURIFICATION BY STORAGE, SEDIMENTATION AND COAGULATION

THERE are comparatively few public supplies of any magnitude in which the water does not require some form of treatment before distribution to the consumers. All surface waters from rivers, lakes, impounding reservoirs, etc., many spring and shallow well waters, and some deep well waters require treatment for one or more of the following reasons :—

1. To remedy pollution, *i.e.*, the removal of colour, odour, suspended matter, organic matter and bacteria.
2. To remove metals, *e.g.*, iron and manganese.
3. To remove dissolved solids, *e.g.*, calcium and magnesium (softening).
4. To neutralise acidity and correct corrosive activity and plumbosolvency.

By employing available processes of treatment, a great many polluted or otherwise unsatisfactory waters can readily be made suitable for drinking and domestic purposes. Some well and spring waters contain, however, so much saline or mineral matter that treatment is impracticable. Thus a number of borehole waters are unusable owing to the presence of an excess of common salt, a few contain an excess of fluoride, and no ready means to remove these constituents are available. Others are so impregnated with sulphates or other substances that they can only be used as mineral or medicinal waters.

In this country, river waters invariably require treatment, and most of the public supplies to large towns are of this character. Owing to the inability of underground sources to meet the increasing demands of the population and industries, greater resort will have to be made to rivers in the future.

The first line of treatment of water supplies is the prevention of pollution so far as is practicable. The subsequent lines of treatment vary according to the individual circumstances, and the efficacy of the methods employed is ascertained by the laboratory examination of samples of the water before and after treatment.

The objects of all treatment are to obtain a clear and bright, colourless, palatable and wholesome water, not too hard and without corrosive and solvent action on metals. Some carefully constructed and protected sources yield such waters without further treatment. The secondary

methods usually employed in this country to obtain such a product are storage, slow sand filtration, rapid sand filtration, with or without the use of coagulants, together with chlorination or other method of sterilisation. Additional measures, such as aeration or activated carbon treatment may be necessary. If too hard, the water may be softened by the lime, lime-soda or base exchange processes. In one or two instances the "excess-lime" process is employed for the simultaneous purification and softening of hard, polluted waters.

Storage. Raw water storage reservoirs serve two main purposes. Large impounding reservoirs are constructed to collect from streams sufficient water in rainy seasons for use throughout the year. Smaller reservoirs holding, for example, a few days' supply, are constructed to equalise the water and tide over periods of unusually heavy rainfall, when river waters may be too turbid or impure for efficient treatment by the normal processes. Some purification of water also takes place during storage, the principal effects being the removal of suspended matter by sedimentation and the destruction of pathogenic bacteria.

The late Sir Alexander Houston studied storage in relation to London's water supply, and in his Third Research Report to the Metropolitan Water Board, the main advantages are summarised as follows :—

1. Storage reduces the number of bacteria (*a*) of all sorts, (*b*) capable of growing on agar at blood-heat, and (*c*) capable of growing in a bile-salt medium at blood-heat, chiefly excremental bacteria.
2. Storage reduces the number of *Bact. coli*.
3. Storage, if sufficiently prolonged, devitalises the microbes of water-borne disease (*e.g.*, typhoid bacteria and cholera vibrios).
4. Storage reduces the amount of (*a*) suspended matter, (*b*) colour, (*c*) ammoniacal nitrogen, and (*d*) oxygen absorbed from permanganate.
5. In the absence of algal troubles, storage tends greatly to lengthen the runs of the filters.
6. An adequately stored water is to be regarded as a "safe water," and the "safety change" which has occurred in a stored water can be recognised by appropriate tests.

7. The use of stored water (*a*) enables a constant check to be maintained on the safety of London's water antecedent to and irrespective of filtration, (*b*) goes far to wipe out the gravity of the charge that the chief sources of London's water supply are from sewage-polluted rivers, and (*c*) renders any accidental breakdown in the filtering arrangements much less serious than might otherwise be the case.

Some of the effects of storage are shown by the analyses included in Table I.

The fate of pathogenic bacteria, such as typhoid bacteria, during storage of water has been described in Chapter XXXIII. At least 90 per cent. of such bacteria present in a polluted water are destroyed in five to seven days, but the remainder may survive for several weeks.

The possible disadvantages of storage were anticipated by Houston when he wrote in the same Report: "Although it would be wrong to

TABLE I
SHOWING PURIFICATION EFFECTED BY STORAGE OF WATER
(Storage for fifteen days approx.)

Chemical Results in Parts per 100,000.	River Thames before Storage.	Chelsea Stored Water.	Reduction per Cent.
Colour Test	83	45	45.8
Turbidity Test	3.50	0.53	84.9
Chlorine	1.67	1.63	2.4
Permanent Hardness	6.82	6.28	7.9
Total Hardness	24.29	23.49	3.3
Oxidised Nitrogen	0.26	0.24	7.7
Ammoniacal Nitrogen	0.0060	0.0022	63.4
Albuminoid Nitrogen	0.0153	0.0108	29.4
Oxygen Absorbed from Permanganate in three hours at 80° F.	0.2127	0.1536	27.8
Bacteria per c.c. growing on Gelatin at 20°-22° C. . . .	4465	208	95.3
Bacteria per c.c. growing on Agar at 37° C. . . .	280	44	84.3
Percentage of Samples containing Bact. coli :—			
In 100 c.c. or less	99.9	57.2	42.7
In 10 c.c. or less	97.7	32.5	65.2
In 1 c.c. or less	83.1	13.4	69.7
In 0.1 c.c. or less	48.3	3.3	45.0

(Houston, "Studies in Water Supply," 1913.)

infer that storage often or habitually or necessarily creates conditions inimical to filtration, there is inevitable danger that prolonged storage, especially if the water remains stagnant, may lead, seasonally or occasionally, to the abnormal and abundant development of vegetable growths; materials harmless in themselves, but resulting in the deterioration of the water as judged by chemical and physical standards, and causative of practical difficulties with its filtration." These anticipations have been fulfilled and have caused much difficulty to waterworks engineers, and dissatisfaction to consumers.

The periodical invasion of stored water by algae leads to inefficiency of filtration and clogging of the filters, or the growth may spread through the sand-beds and appear in the filtrates. The latter causes deterioration in the clarity and organic quality of the water, and the production of objectionable odour and taste which are most difficult to remove. Stored river water which has undergone this change is often so difficult to purify that it may be preferable to suspend the reservoir from service and draw water temporarily direct from the river.

The storage of water in reservoirs necessarily results in the accumulation of organic matter at the bottom. The lower layers of water in deep reservoirs often stagnate for long periods and become deoxygenated. Anaerobic decomposition of the deposited matter may then set in, and

the activities of fungi and bacteria bring about solution of organic matter, production of offensive odours and accentuation of colour. Variations in temperature, by altering the density of the water, give rise to vertical circulation, and the consequent overturn of the water results in the whole volume being fouled by the stagnant bottom layers. Very sudden changes may therefore occur in the quality of the water at a reservoir outlet, causing interference with filtration, and an outbreak of complaints of discoloration, odour and taste in the water supplied to the consumers. To counteract the effects of stratification and seasonal turnover of water in reservoirs, a number of draw-off valves are constructed at different points between the top and bottom levels. By such means, water can be abstracted at the level at which it is most suitable for treatment.

The removal or destruction of bacteria is the most important object in the purification of polluted water. The effective bacterial purification of polluted water by storage requires a long period of time, the duration of which is uncertain. A much more rapid and reliable result is achieved by other means, such as chlorination. Many of the other advantages claimed for storage can be obtained more effectively by the use of coagulants and rapid filters.

The amount of storage required for equalisation depends upon the range of variation in the character of the stream waters. Five to seven days' storage usually suffices, but reservoirs of greater capacity are often provided for other reasons.

The storage capacity which may be necessary to prevent very polluted or turbid river waters being admitted to a purification plant is difficult to determine, but probably the best method is to examine each individual river water from day to day under various climatic conditions, since different intakes vary greatly in this respect. Rivers and streams usually pass the most impure water on the first and second days of flood, after which the water often rapidly improves in quality. Under most conditions five to seven days' storage capacity suffices to avoid the intake of such turbid water as would overload a purification plant, but much depends on the subsequent methods of purification adopted. If, for example, the water is to be slow sand-filtered only, more storage would be required than if coagulants, sedimentation and rapid sand-filtration were also employed.

In the Yarmouth and Lowestoft Bills for taking water from the River Bure and its connected Broads, nine days' storage was prescribed by a Parliamentary Committee in 1907, but in 1920, when the Company again went to Parliament, the compulsory storage was reduced to five days. In this case, in which the river water was not highly polluted, and slow sand-filtration was the method of treatment adopted, it was considered that five days' storage sufficed for all purposes.

In several more recent Water Bills, such as those of the Bedford Corporation, the Southampton Corporation, the Chelmsford Corporation, the Southend Waterworks Company, and the South Essex Waterworks Company, Parliament has adhered to the view that long storage

is unnecessary, and has sanctioned river schemes with raw water storage capacity of five days or less, or even none at all.

River-derived supplies are now almost invariably submitted to both filtration and chlorination, and the filtration is often dual, the water first passing through primary rapid filters, and then through secondary slow filters.

Much of the benefit brought about by long storage is efficiently performed by the primary filters, and these installations are now extensively used in this country.

We are satisfied that, from the point of view of purification, long storage of water is unnecessary and can be substituted with advantage by other methods, such as rapid filtration and chlorination.

There are now, in fact, a number of river-derived waters treated on the above lines, with no raw water storage, which are giving satisfaction as public supplies.

Table II includes a few of the river-derived supplies in this country with little or no raw water storage.

TABLE II
SHOWING RAW WATER STORAGE CAPACITY OF VARIOUS
RIVER-DERIVED SUPPLIES

Authority.	Source of Water.	Amount taken Daily, gallons	Storage, gallons
Bedford Corporation . . .	R. Ouse .	1,500,000	None
Bournemouth Gas & Water Co. .	R. Stour .	4,000,000	None
Bridgwater Corporation . . .	Stream .	540,000	None
Chelmsford Corporation . . .	R. Chelmer .	1,000,000	5,000,000
Chester Corporation . . .	R. Dec .	2,500,000	10,000,000
Exeter Corporation . . .	R. Exe .	3,000,000	6,000,000 or less
Gt. Yarmouth Water Co. . .	R. Bure and Broads .	3,000,000	20,000,000
Hereford Corporation . . .	R. Wye .	1,300,000	4,000,000
Norwich Corporation . . .	R. Wensum .	3,500,000	14,500,000
Reading Corporation . . .	R. Kennet .	2,700,000	None
Sandown Urban District Council	R. Yar .	500,000	2,000,000
Shrewsbury Corporation . . .	R. Severn .	1,500,000	4,000,000
Southampton Corporation . . .	R. Itchin .	10,000,000	None
Southend Water Co. . .	R. Chelmer .	7,000,000	60,000,000
	R. Blackwater		
	R. Ter .		
South Essex Water Co. . .	R. Stour .	10,000,000	31,000,000
South-West Suburban Water Co.	R. Thames .	3,000,000	None
Truro Water Co. . .	R. Trevella .	300,000	None
West Hampshire Water Co. . .	R. Avon .	1,000,000	None
West Surrey Water Co. . .	R. Thames .	1,600,000	1,700,000
Worcester Corporation . . .	R. Severn .	2,000,000	1,250,000
York Water Co. . .	R. Ouse .	4,600,000	8,000,000

The question of adequacy of storage of river waters is therefore limited to considerations of "equalisation," "sedimentation," and "periods of flood and excessive turbidity," and these are so variable in different areas that an opinion can only be given after studying the conditions in each individual case.

When, therefore, it is proposed to abstract water from a river for public supply purposes, considerations with regard to the construction of raw water storage reservoirs are more concerned with engineering and other matters than with hygienic or bacterial purification. Any benefit which is not obtained at the end of five to seven days' storage justifies no further delay, and can be secured with greater certainty by modern purification plants.

The examination of a storage reservoir should include the contributing streams, the surroundings of the reservoir, and its inlets and outlets. The latter should be arranged so as to secure the maximum period of storage available, and to prevent the formation of areas of stagnant water.

Near the coast, and indeed for some miles inland, gulls often congregate at reservoirs, and add much organic and bacterial impurity to the water. Wires stretched across reservoirs a few feet above the surface of the water, even at such wide distances apart as 40 feet, have proved effective in keeping off gulls.

Reservoirs are sometimes stocked with fish with a view to minimising algal growths, but we consider this procedure has more disadvantages than advantages.

The use of bituminous or tarry materials on reservoir banks, fitments and surrounds, should be avoided, since the presence of the minutest traces of these substances causes chlorphenolic odours and tastes in the treated water when chlorinated.

Pure waters should never be stored in open reservoirs. Exposure to light and air inevitably causes deterioration by atmospheric and other contaminations, and by growths of low forms of vegetable and animal life.

Pure water storage reservoirs are generally designed to hold two to five days' supply. They should be carefully constructed and covered to prevent the ingress of any matter or life, and suitably fenced to exclude unauthorised persons. The installation of taps on the inlet and outlet mains of reservoirs is advisable so that samples of the ingoing and outgoing waters can conveniently and properly be collected for examination.

Sedimentation. It has previously been stated that one of the benefits of storage of water is the reduction of suspended matter. With many river waters this is essential, in times of heavy rainfall or thaw after snow, as a preliminary to filtration, otherwise rapid clogging of the filters takes place.

Sedimentation for twelve to twenty-four hours often suffices to remove 90 per cent. of the suspended matter, and the remainder is either deposited very slowly or remains suspended for an indefinite time.

Sedimentation is a good and economical method of removing that suspended matter which deposits quickly, but the remainder, which requires many days of storage to reduce, is best removed by other methods.

The rate at which suspended matter is removed by subsidence depends on many factors, such as the nature of the material, the size and shape of the particles, and the temperature of the water.

Certain substances, such as clay, may be held in water in such finely divided particles that their removal by storage and simple sedimentation is impracticable. Such finely dispersed matter, and also colloidal organic matter, are similarly unremovable by simple sand filtration.

Certain waters, *e.g.*, those of rivers in clay districts and the highly-coloured moorland peaty waters, cannot therefore be effectively clarified by simple storage and filtration. The colloidal matter is efficiently removed only when the particles are coalesced into groups, and this can be effected by the addition to the water of chemicals, known as coagulants, such as the sulphates of aluminium and iron, and sodium aluminate.

Since surface waters are now often treated with little or no storage, sedimentation tends to have greater significance in another sense. It refers more often to the process of collecting together, as a sludge, the chemically coagulated impurities which have been flocculated from the water. In this respect, sedimentation is intimately concerned with the design of plant and tanks. In recent years, much attention has been given, particularly in America, to the design of sedimentation tanks so as to obtain rapid and efficient deposition of the chemically coagulated impurities.

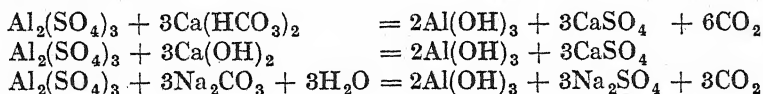
When successful coagulation of a water has been obtained, the coarse coagulum must be so collected that it can be removed as a sludge, while the comparatively clear supernatant water is drawn off for final filtration. The guiding principles in tank design are that the water-flow in the tank shall be uniform and smooth (coarse flocculi must not be disrupted) and of such velocity that precipitated material is induced to settle in a minimum of time. These considerations necessitate the elimination in the tanks of all areas of stagnation. It is only when this last phase of the design is achieved that the practical retention period of a tank most nearly approaches its theoretical value.

The shape and baffling are two main considerations in the design of sedimentation tanks. Tanks of recent design, termed "accelerator" or "precipitator" tanks, combine the functions of flocculation, the promotion of coarse coagulation, and sedimentation. This type of tank is shaped in the form of a cylinder with a conical base, and it is used in both purification and lime-softening plants. The chemically treated water enters at the base, and, while the sludge is withdrawn from this same section, clear water overflows at the top periphery. Other shaped tanks include trough or "hopper" types and rectangular tanks having a great variety of baffling systems.

Coagulation and Flocculation. Chemically, the coagulation of water consists in producing a precipitate of hydroxide of aluminium or iron, or of the aluminate of calcium or magnesium. In its formation, the precipitate breaks down the colloidal solution of the impurities and

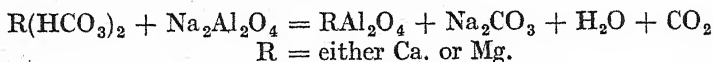
both accumulate into flocculi. The term flocculation describes the mechanical process in which, by means of gentle motion, precipitation is encouraged and coarsened.

Aluminium sulphate, $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$, more commonly known as "alum" or sulphate of alumina, is the most widely used coagulant. It is manufactured commercially by treating bauxite (crude aluminium hydrate) with sulphuric acid. When the bauxite is ferruginous, the aluminium sulphate produced contains much iron and is known as alumina ferric. The aluminium sulphate generally used in water purification contains about 17 per cent. of soluble alumina (Al_2O_3), 49 per cent. of water and less than 1 per cent. insoluble matter. The latter should be less than 2 per cent. It is generally in the form of bricks or lumps but can be obtained crushed and suitable for dry feed plant. A solution, seldom stronger than 5 per cent. is, however, usually made for immediate use, and, owing to its acid character, special precautions must be taken to prevent corrosion of the container tanks and feed lines. Concrete, with an acid-resisting paint or coating, wooden or asphalt-lined tanks are used. Straining of the solution to remove insoluble matter and prevent clogging of jet apertures is advisable. Aluminium sulphate reacts with the calcium bicarbonate present in the water, but it will also react with lime and with sodium carbonate (soda ash), as follows:—



"Black alum," a mixture of aluminium sulphate and activated carbon, has been manufactured in America for the treatment of impure waters, but there is no experience of its use in this country.

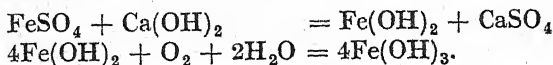
Sodium aluminate, $\text{Na}_2\text{O} : \text{Al}_2\text{O}_3$ or $\text{Na}_2\text{Al}_2\text{O}_4$, probably produces insoluble aluminates of calcium or magnesium:



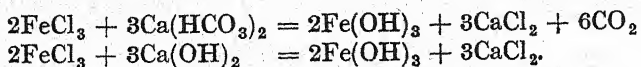
Sodium aluminate contains an excess of soda and gives an alkaline solution when dissolved in water.

The sulphates or chlorides of calcium and magnesium, and also lime, react similarly.

Iron salts produce a precipitate of ferric hydroxide, and ferrous sulphate, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, used in conjunction with lime, reacts as follows:

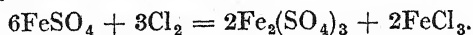


Ferric chloride, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, reacts with both bicarbonate and lime in a similar manner:



Both ferrous sulphate and ferric chloride are deliquescent salts, and the latter is very corrosive. Neither is much used in water purification in this country. Some waters contain iron naturally and this assists coagulation and purification.

Chlorinated copperas, which consists of a mixture of ferric chloride and ferric sulphate, prepared immediately before use by adding chlorine to ferrous sulphate (copperas) solution, is used in a few cases in sewage treatment, but, so far as we are aware, it has not yet been employed in waterworks for the coagulation of impure waters. It is a very corrosive solution. In the preparation of chlorinated copperas the reaction taking place can be represented as follows :



Therefore approximately 1 lb. of chlorine is required for 8 lbs. of ferrous sulphate.

We have frequently advised the use of chalk in conjunction with alumina sulphate. The chalk recommended, called waterworks "precipitated" chalk, is a by-product of the lime-softening process. It is in a fine state of division, relatively cheap, easily handled, and can be apportioned to water by means of a "dry-feed" apparatus.

It is often found that impure river water, having a minimum of impurity, is more difficult to coagulate and clarify than when it is decidedly impure and turbid. The function of the chalk, when used with a water in such circumstances, and in conjunction with coagulants, is probably to provide nuclei on which the precipitated flocculi may form and grow, but it also adds weight and bulk to the coagulated material. In this respect, the chalk may also have a physico-chemical effect in precipitating the colloidal suspension, *i.e.*, it plays a part in the interchange of electrical charges which result in the breaking-down of the colloidal state.

It will be seen that sulphate of alumina deprives water of some of its bicarbonate alkalinity, while the carbon dioxide which is released lowers the *pH* value. This is a disadvantage which must be guarded against in waters already having, or tending to have, corrosive properties on account of calcium bicarbonate deficiency. Lime and soda ash are used to counteract this effect. Sodium aluminate, used alone or in conjunction with alumina, may also be helpful with such waters. The use of waterworks "precipitated" chalk with alumina helps to retain bicarbonate alkalinity, and to prevent depression of the *pH* value, while allowing coagulation to occur. This procedure avoids the addition of an excess of alkalinity which, in coloured, peaty waters, has a tendency to accentuate and fix the colour. This is a common effect of lime addition.

The supersession of the slow sand filter by the rapid filter in water purification has increased the importance of coagulation. Much of the available information on this subject has been collected empirically, and it is largely by an empirical approach that suitable treatment for a particular water is determined. Preliminary laboratory experiment

finds, by trial and error, the suitable coagulant, or mixture of coagulants, which the water requires. It is preferable, when large schemes are under consideration, that these laboratory findings should be confirmed and augmented by field experiments.

In the practical application of chemical treatment, it is essential that the coagulant, or mixture of coagulants, should be immediately disseminated throughout the bulk of the water being treated. This necessity has led to the development of devices facilitating "flash-mixing," *i.e.*, water and chemical dose are rapidly rendered homogeneous.

Flocculation follows the addition of coagulant. The fact that the gentle mixing of a water treated with coagulants facilitates the precipitation of the impurities was always apparent in laboratory experiments, and it was also noticed that coagulum from previous portions of water, when added to another freshly dosed portion, promoted more rapid flocculation. These principles are now incorporated in modern waterworks plant. "Mechanical flocculation" is used, whereby gently rotating paddles, with critical or optimum speeds, keep the dosed water in motion. American workers suggest that, in general, thirty minutes should be the minimum time for this flocculation, and that no useful purpose is served by continuing the process over sixty minutes. The practice of allowing pre-formed "floc" to mix with the freshly-dosed water as it enters the plant is also employed. This mixing of the incoming water with the precipitated salts (in lime-softening) and/or organic impurities (in water purification), is a particular feature of the cylindrical clarifiers previously mentioned. In this type of tank, horizontal zones of water are formed; the water entering at the base meets a "sludge blanket" (material previously precipitated) and the chemical processes are accelerated and carried nearer completion. A clearer and better stabilised effluent is produced and great economy in tank space is obtained.¹

In horizontal flow tanks, care must be taken to avoid irregular flow or turbulence of water, since, if the coagulum is broken up, it will not reform or settle. Careful consideration as to the design and capacity of such tanks is necessary, and periods of four to eight hours' retention of coagulated water are often required to prepare it suitably for filtration. The tanks must be provided with facilities for de-sludging. It is probable that the hopper-bottomed vertical flow tanks mentioned above will replace horizontal flow tanks in many instances, and considerable tendency in this direction is now taking place.

Coagulation is therefore a process by which impure water is prepared for successful purification by rapid sand filtration. The latter, by itself, can do little more than remove suspended matter. It does not remove colour and organic matter nor effect any material bacterial

¹ For further information on this subject the reader is referred to a paper entitled "Application of Experimental Methods to the Design of Clarifiers for Waterworks," by R. Walton and T. D. Key, appearing in the *Journal of the Institution of Civil Engineers*, London, November, 1939.

purification. A combination of coagulant treatment and rapid filtration is required to achieve these results. Even then, bacterial purification may not be sufficient and it is therefore customary to incorporate chlorination in the general scheme of treatment.

Failures in coagulation are fairly frequent in practice, and the commonest causes are the use of alumina sulphate alone, or in incorrect dose, inadequate mixing arrangements, incorrect tank design, or the absence of sufficient reaction and settlement time prior to filtration of the chemically treated water. The latter is a fairly common fault, and sometimes, apparently for reasons of economy in capital costs, alumina sulphate is injected into the water immediately prior to rapid pressure filtration, no mixing devices or tanks being provided. This may be successful, but more often the alumina sulphate reaction takes place during and after filtration, with the result that the sand beds are quickly blocked, and the filtrates develop turbidity, and later, a flocculent alumina deposit. When the purification of impure waters is under consideration it is important, therefore, that analyses and laboratory treatment experiments should be carried out. In most cases, and particularly with surface waters which are subject to fluctuations in character according to climatic conditions, reliance should not be placed on a single analysis but a series of samples should be examined. By such means, invaluable information can be obtained as to the probable efficiency of the proposed system of purification and also of its details, such as the most suitable chemicals to use, their probable appropriate doses, and the flocculation and settlement times required to obtain the best filtration results. Many failures of plant would thus be avoided, and it cannot be over-emphasised that there is no standard plan for all cases and each water must receive individual consideration.

The processes of coagulation and flocculation are also influenced by the physical characters of the water, its dissolved constituents and the temperature. Given suitable mixing arrangements and reaction time, alumina sulphate is usually satisfactory with waters having *pH* values of 6.6 to 7.6, but the addition of a small dose of alkali is advisable at the lower levels in order to obtain a non-corrosive filtrate.

Waters with a bicarbonate deficiency and low *pH* value, such as the soft, acid, coloured upland or moorland waters, are usually best treated by a combination of precipitated chalk and alumina sulphate, followed by the addition of a small dose of lime to the filtered water. Lime or soda ash, added to such waters before the colouring organic matter has been removed, often leads to filtration failures.

Too great a load must not be imposed on rapid sand filters, otherwise clogging of the bed rapidly occurs, and water wastage in back-washing is excessive. If, therefore, the natural and coagulant-produced suspensions are voluminous, measures must be taken by the installation of appropriate tanks, as previously described, to remove the bulk of the suspended matter before the water passes to the filters.

Some river waters are hard and have high *pH* values of the order of 7.8 to 8.4. With these, uneconomically high doses of alumina

sulphate and prolonged retention prior to filtration are often required to obtain satisfactory removal of colour and organic matter. Precipitated chalk with alumina sulphate, good mixing, and retention in vertical flow sludge-blanket tanks prior to rapid filtration, may successfully cope with such waters. Sulphuric acid and alumina sulphate may give satisfactory coagulation with reasonable economy, but there is a reluctance to use sulphuric acid in waterworks treatment. When the purification of hard, impure waters of this character is under review, careful consideration should be given to the "excess-lime" process (see Chapter XLII), as an alternative to coagulation and filtration. By this process, the water is both purified and softened, and the advantages of softening may more than balance the additional costs of treatment, if any.

Coagulation is retarded by low temperatures, and inferior results are, therefore, more likely to be given by coagulant treatment and rapid filtration during the winter months. In addition to the retardation of the chemical reactions by cold, there is reduced biological activity on the sand beds, and this has some effect, even in rapid sand filters.

CHAPTER XXXIX

THE PURIFICATION OF WATER BY SAND FILTRATION

FILTRATION of water through sand is one of the earliest methods of water treatment and is an essential part of practically all water purification works.

Sand filters are classified into two groups, *i.e.*, the slow and the rapid, according to the rate of filtration employed, but, as will be described later, there are other fundamental differences between the two types. The slow sand filter was developed in this country following its introduction for the treatment of London's water supply in 1829. The rapid sand filter is, however, of more recent date, having been developed during the past fifty years by pioneer work carried out mostly in America. Its introduction arose from the frequent unsuitability of slow sand filters for the treatment of impure surface waters, such as those derived from most rivers, the general inflexibility of slow sand filters, their failure in cold climates, and the extensive acreage necessary for the treatment of large supplies.

The value of the slow sand filter was established in London by the fall in the incidence of water-borne diseases such as cholera, dysentery and enteric fever, and its use extended rapidly in this country and abroad. For the reasons already stated, and in view of the development of coagulant treatment and chlorination, rapid sand filters are now in more common use than slow sand filters. The latter are, in fact, becoming obsolete, for there are few instances in this country where rapid filters, with the accessory processes of coagulation and chlorination, cannot be more suitably and efficiently applied.

When considering the relative merits of these two forms of filtration, an important fact is the greater flexibility of the rapid filter system and its amenability to control. The slow sand filter depends substantially on biological activity for its efficiency and is, therefore, largely controlled by climatic conditions. Also, many surface water sources now utilised for public supply purposes, such as rivers in upland and moorland areas, yield highly coloured waters, and colour is not materially reduced by slow sand filtration.

It is therefore seldom that slow sand filters are now constructed in new waterworks of any magnitude, although they are still in use in many of the older works, chiefly on account of the loss in capital which would result from their abolition. Slow sand filters can, however, be suitably installed when the waters to be treated are only lightly contaminated and have no noticeable colour; where winters are not severe, and in small supplies where it is impracticable to give constant skilled attention to treatment plant.

The detrimental effects of cold weather on sand filters can be

restrained by suitable housing of rapid filters, and covering of slow sand beds. The latter is not often carried out in this country, except in small units, but is more common in North America and other countries where winters are severe.

Slow Sand Filtration. Slow sand filters consist of brickwork or concrete basins, usually rectangular in shape, on the bottom of which are brickwork channels, perforated pipes, or other under-drains, supporting gravel on which rests a bed of sand. The sand must be carefully selected and graded, and should consist of hard, durable grains, free from impurities such as clay, iron, sulphates, phosphates and organic matter. Grading is of particular importance, and the sand should not contain an undue proportion of either very fine or very coarse grains. Specifications for filter sand often include reference to the "effective size" and the "uniformity co-efficient." The size (in mm.) of the mesh of a sieve which retains 90 per cent. (by weight) of the sand and permits 10 per cent. to pass through is the "effective size" of the sand and this, in the British Specifications, is 0.35 mm.

The size (in mm.) of the mesh passing 60 per cent. (by weight) of the sand, divided by the "effective size" of the sand (in mm.) is the "uniformity co-efficient" which, in the British Specifications, is 2.5 or less. The "effective size" is intended to limit the depth of the fine sand on the top of a filter, whilst the "uniformity co-efficient" provides for a sufficient depth of sand of uniform grading. Considerable variations are found in the sands of different filters, the "effective size" varying from 0.2 mm. to 0.5 mm. and the "uniformity co-efficient" from 1.5 to 3.

Slow sand filters are usually 9 to 10 feet in depth, 1 to 2 feet being occupied by the under-drainage system and gravel, 2 to 3 feet by sand, with 4 to 5 feet of water on the surface. The under-drainage system must be carefully arranged so as to draw off the filtered water as evenly as possible from the whole of the bed. The inflow of raw water should similarly be evenly admitted so as to avoid local disturbance of the sand surface. The sand bed should be graded somewhat as follows:—

10 per cent. having grains of 0.2 mm. to 0.34 mm. in size.

50 " " " " " 0.35 " " 0.8 " " "

25 " " " " " 0.81 " " 2.0 " " "

15 " " " " " 2.1 " " 5.0 " " "

The rate of flow through the bed, which is from above downwards, varies according to the condition of the raw water, and is usually between 2 and 6 inches per hour, corresponding to approximately 1.1 to 3.3 million gallons per acre per day. A filtering speed of 4 inches per hour is common, and higher speeds, even in excess of 6 inches per hour, have been employed. In our experience, there are few waters which can be efficiently treated at such high speeds, and in many instances 2 inches per hour should not be exceeded. Each individual case must be decided on its merits according to the clarity and organic purity of the water to be treated and the processes of treatment employed in addition to slow sand filtration. The higher speeds can be used for the filtration

of water which contains little suspended matter and has only slight organic and bacterial impurity.

Waters which are highly coloured should not be treated by slow sand filtration, and those containing, regularly or intermittently, significant organic and bacterial contamination should be filtered only at slow rates of 2 to 3 inches per hour.

An example of the results obtained in the slow sand filtration of a water with high colour is given below :—

Averages	Raw Water	Filtered Water
Colour, Hazen scale	80	70
Albuminoid ammonia, parts per 100,000	0.018	0.011
Oxygen absorbed : 4 hours at 80° F., ,, ,,	0.66	0.58

If the water contains distinct traces of suspended matter, rapid clogging of the sand bed takes place, and such water should therefore be partially clarified in sedimentation basins prior to filtration.

Turbidity due to very finely divided suspended matter may pass through the filter unless pre-treatment is employed, or the filtration speed is carefully adjusted. In some instances, pre-treatment by rapid sand filters is undertaken to relieve the load on the slow sand beds and permit their operation at increased speed. Existing waterworks provided with slow sand filters may, for example, when called upon for a greater output, instal rapid sand filters to permit a higher speed of operation of the slow sand beds, thereby avoiding the construction of further beds and achieving economy in space and costs.

The following figures show the results obtained in an installation

DOUBLE FILTRATION

Averages	Raw Water	Primary Filtered Water	Secondary Filtered Water
Turbidity, Silica scale (p.p.m.)	2.7	0.5	0.0
Colour, Hazen scale	21	16	13
Albuminoid ammonia (parts per 100,000)	0.023	0.016	0.010
Oxygen absorbed, 4 hours at 80° F. (parts per 100,000)	0.206	0.169	0.130
Bacterial count on agar. 1 day at 37° C. per ml.	165	99	32
Percentage of samples containing coliform bacteria in :—			
100 ml. or less	100	100	40
50 ml. or less	97	90	10
10 ml. or less	90	40	0
1 ml. or less	33	7	0
0.1 ml. or less	3.3	0	0

employing double filtration, *i.e.*, rapid sand filtration at a rate of 100 gallons per square foot per hour, without preliminary coagulation, followed by slow sand filtration at a rate of 2 million gallons per acre per day. The raw water, derived from a river, has pH 7.5 to 8.0 and total hardness (mostly temporary) of 24 to 30 parts per 100,000. The figures are the averages of 31 samples in each of the three series.

Even if suspended matter has been mostly removed by sedimentation or pre-filtration, too high a speed must not be employed in the slow sand beds, otherwise they operate merely as strainers and effect no significant organic and bacterial purification.

Since the development of chlorination, there has been a regrettable tendency to underestimate the value of organic purification of water, and to operate slow sand filters at an unduly high speed. This results in a strained water, reasonably clear in appearance, but of a low standard of organic purity, and reliance is placed on chlorination to obtain the required standard of bacterial purity. Except in emergency, we deprecate this tendency and consider that removal of organic matter is a very important part of water purification. The presence of organic matter impairs the efficiency and reliability of chlorination, conduces to the development of odours and tastes in the water supply, and promotes the formation of organic deposits in the mains and reservoirs of the distribution system, in which growths of low forms of life are encouraged. If, therefore, suitable organic purification cannot be effected by slow sand filters when operated at the speeds permitted by the circumstances, treatment by coagulants, settlement and rapid filtration should be employed.

Double filtration is often required for the efficient treatment of river waters, and, if the latter are both impure and hard, the excess-lime process provides an alternative method of treatment in which purification and softening are simultaneously obtained. Double filtration may consist of rapid sand filtration, with or without coagulation, followed by slow sand filtration or rapid sand filtration. In America, crushed anthracite coal has been used in filters instead of sand, but there is no experience of its use in this country. Graded gravel is occasionally used for "roughing" filters or coarse strainers prior to slow sand filters.

Slow sand filters should be equipped with control valves by means of which the rate of flow can be adjusted and kept reasonably uniform. These are usually hand-operated but automatic flow-controls are sometimes installed. Instruments recording the rate of flow and the loss of head are also used, the necessity for the cleansing of a bed being indicated by the latter.

Individual slow sand filters may be of such large size as $\frac{3}{4}$ to 1 acre, but it is advisable that the total filtration area at any works should be divided into a number of units so that, when any one is out of service for cleaning or sand replenishment, the remaining area is sufficient to avoid an unduly high rate of filtration.

Purification by slow sand filtration is effected by the processes of natural flocculation and sedimentation of suspended matter, adsorption,

mechanical straining and biological activity. The time factor, *i.e.*, speed of filtration, is of considerable importance in the flocculation of colloidal and suspended matter. The efficiency of removal of these matters depends on the relative sizes of the particles and the interstices of the sand bed. With very fine sand, the interstices are so small that the bed rapidly becomes choked, and, with unduly coarse sand, the interstices are so wide that suspended particles pass through the bed and appear in the filtrate. Biological activity plays a pre-eminent part in the purification of water by slow sand filters and it is much influenced by temperature. This accounts for the inferior filtration results obtained in cold weather when biological activity is at a minimum.

Numerous forms of vegetable, animal and bacterial life take part in this process and the surface of the sand bed becomes uniformly covered with a biological coating or mat. It extends for an inch or so into the top layer of the sand, the grains of which become enveloped and the interstices restricted. In their metabolism, these organisms remove organic matter and bacteria, oxygenate the water and oxidise ammoniacal nitrogen to nitrates; in fact, the nitrogen cycle of the soil takes place on sand filters.

The greater part of the purification effected by slow sand filters takes place therefore in the top few inches of the bed. Should the biological growth be excessive in amount, or unsuitable in the species of life present, the sand bed may be rapidly clogged. In other cases when conditions are unsatisfactory, small unicellular algæ or protozoa permeate the bed and pass through in the filtrate, producing therein turbidity, colour or odour. Fungus growths of *Sphærotilus* type may behave in similar manner, particularly in organically impure waters.

When the water on the top of the sand beds obstructs sunlight by turbidity or colour, unsuitable biological growths are likely to develop and impair filtration.

Slow sand beds require periodical cleansing in which the top layers are scraped off and a fresh surface of sand exposed. The frequency of scraping depends on the amount and character of the biological coating, and the amount of suspended matter passed on to the bed by the water. In some instances, and at certain times of the year, scraping will be required after ten to fourteen days' use, whilst in others, runs of three to five months may be possible with satisfactory results. Inferior filtration results are often initially obtained with a freshly scraped bed, and in order to minimise this defect an unusually slow rate of filtration is temporarily employed. Scraping is generally repeated on several occasions before the removed sand is washed and replaced. It is advisable that the sand bed should not be reduced by more than a foot before replacement.

In all such operations on filter beds, workmen must be carefully selected and instructed, be cleanly in habit and provided with suitable cleansed gumboots, worn solely on the work in question.

Rapid Sand Filtration. Rapid sand filters are of two types, the open gravity filter and the closed pressure filter. When circumstances

permit, the former is to be preferred, since there is advantage in having the filter under ready observation, but, for engineering and economical reasons, the closed pressure filters are often used.

Rapid filters occupy very little space compared with slow sand filters, since, as their name implies, the rate of filtration is much greater, being 40 to 50 times that of slow beds. They can therefore be conveniently housed and protected from undue interference by climatic conditions. The speed of filtration varies from 60 to 150 gallons per square foot per hour, according to the character of the water to be filtered. A rate of 100 gallons per square foot per hour, which is equivalent to approximately 105 million gallons per acre per day, is fairly general practice. The total filtration area employed is divided into a number of units (the whole often known as a battery), so that, when a unit is stood off for washing, the total available area is not unduly depleted. In many cases where the total daily supply is filtered in, say, 8 or 10 hours, the whole of the units can be washed at the same time during the resting period, but some installations operate practically continuously throughout the day.

Contrary to slow sand beds, rapid filters are frequently washed, in some cases daily, in others weekly, depending on the character of the water under treatment. Filtration is downwards, and washing of the sand beds is upwards.

A unit consists of a chamber, usually of concrete in the open gravity filters, and a steel cylinder in the closed pressure filters, containing a bed of sand resting on gravel, with suitable water distributing arrangements at the top and under-drainage system at the bottom. Special care is necessary in the latter arrangements to ensure uniform distribution and draw-off of water, and the under-drainage system must also be designed to permit of back-washing, in which clear or filtered water is used and the rate of flow of water is very high. Also, in some rapid filters, provision is made for the admission of compressed air as part of the back-washing process. In others, mechanical means are employed to agitate the sand bed during washing. The units are also equipped with valves and controlling gear together with instruments recording rate of flow and loss of head. Equipment for controlling flows is sometimes automatic, and when a unit is returned to service after washing, the initial rate of flow is reduced for a sufficient period of time to permit settlement and compacting of the sand bed. After washing, units should preferably be rested for an hour or so, and, when returned to service, started at a slow rate, the first filtrates being run to waste.

The sand bed should consist of carefully selected clean sand of suitable grade and durability. The sand must not be so fine as to obstruct unduly the flow of water nor so coarse as to permit the passage of finely divided "floc" or suspended matter. The "effective size" usually specified is between 0.4 mm. and 0.6 mm. and the "uniformity co-efficient" not more than 1.7. The depth of the sand bed is usually $2\frac{1}{2}$ to 3 feet, the supporting layer of graded gravel 1 to $1\frac{1}{2}$ feet and the depth of water on top of the sand 3 to 4 feet.

Rapid sand filters are used in various ways for different purposes. For the removal of traces of suspended matter from an organically pure and colourless water, they can sometimes be used without preliminary coagulation processes and settlement tanks. They are in common use for the removal of the minute traces of suspended chalk which remain in a lime-softened water, and occasionally as pre-filters for the reduction of suspended matter in water passing to slow sand filters. For the purification of polluted water, *i.e.*, the removal of colour, organic matter and bacteria, coagulation with flocculation and settlement tanks are essential accessories to rapid sand filters. Rapid filters used otherwise do not remove colour, organic matter and bacteria but act merely as strainers removing suspended matter.

The following figures are examples of the results obtained at two rapid filter installations, one using no coagulants and the other using powdered chalk and aluminium sulphate with two hours' retention of water before filtration. Both waters have high *pH* value of 7·8 to 8·2 and total hardness of approximately 22 parts per 100,000.

Averages	Rapid Filtration without coagulation			Rapid Filtration with coagulation		
	Raw Water	Filtered Water	Percentage Removed	Raw Water	Filtered Water	Percentage Removed
Turbidity, Silica scale (p.p.m.)	3·2	0·8	75	15	0	100
Colour, Hazen scale . .	19	16	—	25	Under 10	—
Albuminoid ammonia (parts per 100,000) . .	0·036	0·032	11	0·028	0·016	43
Oxygen absorbed (parts per 100,000)	0·280	0·265	5	0·295	0·166	44

Given an efficiently coagulated and settled water, rapid filters are convenient and effective, and this combination of processes is much more flexible and controllable than slow sand filters for the purification of impure waters. By these means, considerable improvement in bacterial purity is obtained, but chlorination has now become almost an integral part of treatment, and covered clear water tanks, which also serve the purpose of chlorine contact tanks, should therefore be incorporated in such installations.

To obtain reasonable efficiency and economy in rapid filter installations, the incoming water must not be unduly turbid or highly infected with algæ. Care must therefore be exercised in suitably preparing the water for filtration by the use of coagulants and tanks. It is quite common to find filtration failures brought about by inefficient preparation of the water owing to insufficient or improper coagulants, defective mixing, or inadequate flocculation and settlement. Instances are frequent in which a dose of aluminium sulphate is administered in a pressure system immediately prior to the inlet of the water to the filters, with results which are seldom fully satisfactory, the filtrates

retaining colour and suspended matter and forming flocculent deposits due to aluminium sulphate reactions occurring during and after filtration. The importance of completing such reactions prior to filtration is emphasised and, as described in Chapter XXXVIII, preliminary experiments should be carried out with every individual water to ascertain the most suitable coagulants and the approximate tank capacity necessary to obtain suitable conditions for filtration.

Attention must also be paid to the pH value of the water. With the soft, acid, peaty, coloured, surface waters often used in the North of England and other moorland areas, the use of chalk in association with aluminium sulphate in the preliminary coagulation and sedimentation treatment, together with the administration of a small dose of lime to the filtered water, are required to obtain satisfactory results and correct plumbo-solvent and corrosive tendencies.

Odours and tastes are not always removed by coagulation, settlement and rapid sand filtration and additional treatment may be required. Preliminary aeration may be beneficial, but some instances, especially those due to algal products, may require special methods, such as activated carbon treatment or superchlorination and dechlorination. Hydrogen peroxide, potassium permanganate and ozonisation are also occasionally used for the removal of odours.

Although purification by rapid sand filters is substantially a process of mechanical straining and adsorption, in which the presence of a little alumina "floc" on the surface grains of the sand bed plays an important part, there is some evidence of biological activity when temperatures are suitable. In the summer months, for example, we have often observed the disappearance of ammoniacal nitrogen from water during rapid filtration. This may be explained by its conversion to nitrates as a result of biological action, since the effect is not observed in the same filters during the winter months. Temperature exerts an important influence on both coagulation and filtration, cold being detrimental in both respects. Purification plants must therefore receive extra attention during the winter months, particularly since the least satisfactory conditions of the raw waters may also arise at that season.

The rapid sand filter has now become firmly established in British waterworks practice and there are very few waters utilised for public supply purposes which cannot be suitably purified by rapid filtration and its associated processes in preference to the older method of slow sand filtration. The development of the rapid filter has led to considerable economy in capital costs in replacing large raw water storage reservoirs and slow sand filters. It serves many purposes including the removal of suspended matter as a preliminary to slow sand filters, the filtration of unpolluted waters which are not clear and bright, the filtration of polluted waters after coagulant treatment, the removal of suspended chalk from lime-softened waters, and the removal of iron and manganese from waters in which these metals have been precipitated by aeration or chemical treatment. It is also invariably used in swimming pool water purification plant.

For special purposes, which will be described in later pages, units resembling rapid filters are used and contain iron-removing material such as "Polarite," acidity-removing material such as magnesite, or activated carbon for the removal of odour or free chlorine.

Careful control of processes is necessary in all water purification installations. Suitable taps should be fitted so that samples of the water can be collected for testing purposes at each stage of treatment, from the raw to the final water. Each filter unit should be equipped with a sampling tap so that individual defects can be detected. Plant personnel should be trained and a laboratory should be provided at all waterworks of any magnitude.

CHAPTER XL

THE BACTERIAL PURIFICATION OF WATER BY PHYSICAL AGENTS, OZONE AND METALS

Heat. The boiling of water is an absolute safeguard against infection by bacteria of water-borne disease. These bacteria are, in fact, destroyed when the temperature of the water has reached approximately 80°C. , but raising the temperature to boiling point is safer.

It is sometimes necessary in the case of small private supplies, and also as an emergency measure in public water supplies, to advise consumers to boil the water before use for drinking and domestic purposes. Just bringing the water to the boil suffices, and prolonged boiling is unnecessary and wasteful.

Boiling renders water less palatable, and also less attractive in appearance owing to the precipitation of chalk, iron, etc. causing turbidity and deposit.

Various apparatus employing heat for the destruction of bacteria have been introduced for the treatment of small supplies of water in military and civil practice. The process is impracticable for large-scale use.

In certain arid isolated parts in North-East Africa and elsewhere, distillation of saline water is employed to obtain drinking water supplies.

Cold. It is often thought that bacteria are destroyed by freezing, but this is not the case, although their multiplication is arrested. It has been shown that the exposure of certain bacteria to a temperature of -252°C. leaves them viable and apparently unaltered. Also, the work of Houston and others indicates that pathogenic bacteria, such as *Bact. typhosum*, actually survive longer in water at low temperatures than at ordinary temperatures.

Ice may contain numerous viable bacteria, and water of the highest standard of purity should be employed for the manufacture of ice intended for use with food and drinks.

Light. Sunlight has some power of destroying bacteria in water, but, owing to climatic conditions, its action is not marked in this country. In tropical countries, however, it is an important factor in the self-purification of rivers, and, as was noted by Clemesha in India and other workers in hot climates, it is partly responsible for the rapid disappearance of streptococci and certain intestinal bacteria from water.

The ordinary rays of sunlight play little part in this action, which is due almost entirely to the ultra-violet radiations assisted by the heat rays. It has been suggested that the bactericidal action is due to oxidising substances such as ozone and hydrogen peroxide produced

by the agency of the rays. There is evidence that the presence of oxygen is necessary for the germicidal activity of ultra-violet rays.

Under suitable conditions, ultra-violet rays are actively bactericidal, but they have little penetrative power and are obstructed by dust, etc. in the atmosphere, by glass and by water. Quartz is transparent to the rays.

Artificially produced light, rich in ultra-violet rays, has been employed for the sterilisation of drinking water, and the Cooper-Hewitt Mercury Vapour Lamp was designed and used for this purpose. Our investigation of this process, whilst showing that good bacteriological results could be obtained under ideal working conditions, led us to the opinion that its application to public water supplies was impracticable owing to working difficulties and high cost.

Owing to the low penetrative power of ultra-violet rays, the water to be treated must be bright and free from colour and suspended or colloidal matter. Even then the zone of penetration is less than 1 foot. All the water must pass, therefore, as a thin layer, in close contact to the lamps, so as to come entirely within the influence of the rays.

The process was operated at several waterworks in France, at Amiens, Luneville, etc., but, for the reasons stated above, it has not been adopted on any large scale, and has found no favour in waterworks practice in this country.

Hydrogen Peroxide. Hydrogen peroxide, H_2O_2 , by breaking up and liberating nascent oxygen, purifies water and destroys bacteria, but its action is too feeble for practical use, and it is also too costly and unstable. It is occasionally used for the removal of odour from water.

Ozone. Ozone, an allotropic form of oxygen in which three volumes of O_2 are condensed to two volumes of O_3 , is said to occur in the atmosphere in small amounts, and to be formed by the action of ultra-violet rays on oxygen. It is also present in the oxygen liberated by many chemical reactions; during the slow oxidation of phosphorus, and in the electrolysis of acidified water. The odour noticed in the vicinity of certain electric apparatus is due to ozone formed by the action of the silent electric discharge on the oxygen in the atmosphere.

Ozone, whilst not unpleasant in minute amount, has a distinctly irritating odour, suggesting sulphur dioxide or chlorine, when present to any appreciable degree in the atmosphere, and it causes headache. It is unstable with heat, and decomposes gradually at ordinary temperatures. Ozone is soluble in water to the extent of only 1 volume in 100 volumes at ordinary temperature and pressure, and it slowly decomposes in water. Its presence in water can be detected by the iodide-starch test, for, like chlorine and other oxidising agents, ozone liberates free iodine from potassium iodide. It can also be detected by the orthotolidine test, as used for free chlorine.

Ozone is a powerful oxidising agent, bleaching agent, and bactericide.

The development of the electric process has led to the production of ozonised air on commercial lines, permitting the economic use of ozone in water purification, and as a bleaching agent in certain industries.

Although little used for water purification in this country and America, ozonisation has considerable application elsewhere, and, in France, some ninety ozone installations treat approximately 200 million gallons of water daily. The following are amongst the largest municipalities employing the process (Whitson, 1940) :—

Paris	.	.	.	.	.	60 million gallons daily.
Nancy	.	.	.	.	.	22 " " "
Nice	.	.	.	.	.	18 " " "
Toulon	.	.	.	.	.	11 " " "
Leningrad	.	.	.	.	.	11 " " "

Ozonisation is essentially a "finishing" process, and it can improve the water in several respects. When applied efficiently in suitable cases it has the following effects :—

1. Bacteria are destroyed. Although sterilisation may not be complete, the water is of a sufficiently high standard of bacterial purity for public supply purposes. As in all other cases, the treated water should be carefully protected in storage and distribution since no bactericide remains to counteract any bacterial contamination which may take place subsequent to treatment.

2. Colour, a character of water which often resists removal by other methods of treatment, is reduced.

3. Certain odours and tastes are removed. Treated waters, particularly those derived from surface sources, often retain earthy or musty odours. Ozonisation may therefore eliminate the need for activated carbon or other remedial measures employed in such cases. It improves the palatability of the water, giving "sharpness" in place of the "flatness" which is so common in treated surface waters.

4. The organic matter present in the water is oxidised and growths of low forms of life in mains and service reservoirs are therefore restrained.

5. Since the ozone added to the water decomposes into oxygen it can be claimed that no "foreign" substance is present.

The contact time required to effect these improvements is comparatively short, being between five and ten minutes.

In commercial and water treatment plants, ozone is produced by passing a silent electric discharge through dry, cool air. If moisture is present, oxides of nitrogen are formed, and at raised temperatures, the decomposition of ozone is accelerated. The air supply is dried by refrigeration, or by being passed over anhydrous calcium chloride or silica gel. These reagents can be dehydrated by heating, and reused. Cooling of the air is required only in hot climates.

There are several types of ozone-producing plants. One type consists of a series of rectangular metal electrodes which are hollow so that they can be cooled by internally flowing water. On the outer surfaces of the electrodes are closely contacted sheets of glass which serve as dielectrics. Each element of a producer consists of one high tension and one low tension plate and the elements are arranged

in groups of varying number up to twenty-four, the groups being fitted in glass casing with inlets and outlets for air and ozonised air respectively. Both the high tension and the low tension plates are water-cooled and special provision must be made to insulate the water inflow and outflow. The electrical requirements of this type of producer are an alternating current, a voltage of 20,000 to 22,000, and a frequency of 500 cycles per second. In small plants, it is not economical to change the frequency of the mains supply (usually 50 cycles) but the voltage is raised by a transformer.

Another type of producer employs a central cylindrical metallic electrode (the high tension electrode) supported symmetrically within a glass cylinder which acts as the dielectric. The glass cylinder is jacketted in cooling water, and the outer casing, which is earthed, constitutes the low tension electrode. The cylindrical elements are arranged in groups of three to seven in single water-jackets. The voltage used is 7,000 to 8,000 and the normal frequency of the mains is taken.

In both these types of producer, the air flows between the high and the low tension plates and is ozonised by the passage of the silent electric discharge. It then contains from 1 to 9 grammes of ozone per cubic metre, according to the conditions of production, or approximately 0.1 to 1 per cent. of ozone by weight.

The dose applied in water purification is of the order of 2 parts per million of ozone. Therefore, using ozonised air containing 5 grammes of ozone per cubic metre and applying a dose of 2 parts per million, 1,500 cubic metres of ozonised air are required for the treatment of a million gallons of water. This quantity is equivalent to approximately one-third of the volume of water treated.

The next stage in the process consists of the mixing of ozonised air and water. This mixing must be intimate and the rapid dispersal of the relatively large volume of gas throughout the water is a difficult problem. Of the two methods in common use, one employs an emulsion system based on the injector principle, *i.e.*, that employed in the laboratory filter pump and the injector used for dissolving chlorine gas in solution feeds. This emulsion type of mixing involves a minimum loss of head of 12 feet, and, therefore, either the plant must be in such a position that this loss of head is of no consequence, or double pumping of the water must be employed.

The other method of mixing is to pass the ozonised air upwards through a tower in which the water descends. The tower can be baffled to improve mixing but its height must be limited owing to the fact that the ozonised air is injected under pressure, and too great a pressure causes a rise in temperature which decomposes the ozone. The air emerging from the top of the tower may contain an appreciable quantity of ozone, when it is advantageous to return it to the drier and ozonising plant. The minimum loss of head in this method of diffusion is $2\frac{1}{2}$ feet.

Ozonisation presents certain advantages as a process of water

treatment, but it is not so generally applicable as chlorination and is more complicated and costly. The plant requires skilled attention, and, arising from the use of electric current, precautions must of course be taken to prevent accident to personnel. In view of the dependence of the process on a constant supply of electric current which, being generally taken from the mains, is liable to occasional failure, provision should be made either for an alternative supply of current or a stand-by chlorination plant. Care must be taken to prepare the air supply suitably, otherwise inefficiency results. The difficulties involved in the introduction and dispersal of the ozonised air throughout the water, and the loss of head resulting, have already been mentioned.

In considerations of costs, the price of electricity is an important item, but it must not be overlooked that ozonisation has the additional advantages of removing colour and odour. In carefully selected cases, it may therefore be possible to substitute ozonisation for several processes employed following filtration, such as chlorination with dechlorination or activated carbon treatment. A disadvantage of ozonisation is the absence of a rapid, simple and reliable test to verify the adequacy of the dose. A fluctuating ozone yield of the plant may aggravate this disadvantage. Confirmation of the efficacy of treatment must therefore be obtained by frequent bacteriological examinations of the final water.

There is, however, a place for ozonisation in water purification, and the process should be carefully considered whenever new purification works are being planned. In this country, there are at present a few public water supplies and also a number of swimming pool waters successfully treated by ozonisation, and it is anticipated that, with improvements of plant and fall in the costs of electricity, further extension will take place in the future. The attractive appearance of ozonised water in swimming pools is of particular appeal.

Metals. Koch, in 1881, drew attention to the antiseptic properties of the salts of metals, particularly of the heavy metals mercury and silver, and these substances have been extensively used in medicine as disinfectants.

The real disinfecting agent was shown to be the metallic ion (Kronig and Paul, 1897), and the toxicity of the metallic salts depends therefore on the degree of dissociation and is proportional to the concentration of free metallic ions.

Mercuric chloride or corrosive sublimate is a powerful and poisonous disinfectant, and toxic properties are accorded in more or less degree to all the heavy metals.

The salts of the heavy metals have been used to some extent in water treatment. Copper sulphate is often employed as an algicide and iron and aluminium salts as coagulants, but they have not been found to possess any significant bactericidal properties.

The bactericidal and antiseptic action of metals has often been noted. Delepine and Greenwood (1914) investigated this subject and drew attention particularly to the sterilising action of copper.

Wilson (1922) also observed the sterilising action of this metal in water. The bactericidal property of distilled water prepared from copper stills, and hence containing minute traces of copper, is well known.

The use of the metals silver and aluminium in the sterilisation of drinking water supplies was considered some years ago, but, owing to the slowness of action and other objections, the process was abandoned.

Some bacteria are more sensitive to one metal than to another. Thus, it has been found that copper is more toxic to *Bact. coli* than to typhoid-paratyphoid bacteria, while the reverse is the case with silver. Also, it would appear that typhoid-paratyphoid bacteria are more tolerant than *Bact. coli* to bismuth.

Many views have been advanced as to the mode of action of the metallic ions in destroying bacteria, but it appears to be due to the formation of a compound between the metal and the bacterial protein, which renders further life and multiplication impossible.

Katadyn Silver. Dr. Krause, of Munich, demonstrated that the bactericidal properties of metals could be enhanced, and, in 1929, he introduced an activated form of silver to which he gave the name "Katadyn." He claimed that the metal in this form was highly toxic to bacteria, and he suggested its use as a practical means of sterilising water supplies, since such minute amounts as 0.00001 gm. per litre sufficed to destroy bacteria suspended in water.

It was proposed by Krause that the addition of the activated silver to water should be effected by bringing the water in contact with surfaces to which the silver had been made to adhere, and, amongst other things, he prepared a quartz sand the grains of which were covered with Katadyn silver. Sterilisation could, it was claimed, then be secured by passing the water through a filter bed of this sand, the effective life of which was said to be considerable.

In view of the claims made for this process in which it was said a sterile filtrate, unimpaired in appearance, palatability, etc., was obtained, we gave it close attention, and some of the results of our experiments and the conclusions drawn therefrom were reported in the Official Circular of the British Waterworks Association (Suckling, 1931).

The amount of silver taken up by water after passage through a Katadyn sand filter varies from 0.0015 to 0.006 parts per 100,000, and water containing this minute amount of silver can probably be consumed with impunity. There are, however, objections to the habitual consumption of water containing silver.

The bactericidal efficiency of the process depended firstly on the rate of filtration, but a rate equivalent to, or even greater than, that employed in rapid sand filters was effective. The water leaving a filter, even when filtered at slow sand filtration rate, was not however adequately sterilised, and a subsequent period of storage, *i.e.*, contact time, was required. The silver taken up by the water was found to be slow in destroying bacteria, and a period of time of two to twelve hours subsequent to filtration was required before water, polluted

to an extent commonly found in practice, reached an adequate stage of sterilisation, *i.e.*, *Bact. coli* absent from 100 c.c.

The early results were encouraging, and with distilled water or very pure natural water artificially contaminated with bacteria, substantial confirmation of Krause's claims was obtained.

In addition to coliform bacteria, the ordinary "water bacteria," both those growing on agar at blood-heat and on gelatin at 20° C., liquefying and non-liquefying varieties, were readily destroyed. Spore-formers were more resistant but were reduced in number. Pathogenic bacteria, such as typhoid-paratyphoid-salmonella-dysentery bacteria, proved as susceptible to destruction by silver as *Bact. coli*.

The treated water, owing to the presence of silver, retained its bactericidal property and bacteria subsequently added were destroyed. The development of algæ was also prevented. These effects would be limited in practice owing to the adsorption of the silver on the surfaces with which the treated water came in contact.

It was found that many factors likely to operate in practice interfered with the process and prevented sterilisation. For example, a water must be clear, bright and colourless, since the presence of any suspended or colloidal matter adsorbed, coated, or otherwise affected the silver so that its sterilising action was prevented. Also, the sand of the filter bed soon became impaired and ceased to impart any silver to water passed through it. A high organic content of the water, or the presence of iron or sulphuretted hydrogen, were also detrimental.

Temperature was found to exert an appreciable influence on the process, the velocity of sterilisation being increased as the temperature was raised. In the region of 0° C., bactericidal activity was insignificant in twenty-four hours and became too slow therefore for practical application.

Also, contact of the treated water with various substances, such as vegetable growths or iron rust, as may take place in tanks, reservoirs and mains, removed or interfered with the action of the silver and prevented sterilisation. The water thus became de-activated both as regards bacteria and algæ.

The silver was also readily removed from the Katadyn-sand filtered water by filtration through ordinary sand, carbon or base-exchange softening material, and also by lime-softening. Any such process must therefore precede and not immediately follow silver treatment.

Aeration helps sterilisation by silver, and a deoxygenated water is unsuitable for the treatment. Oxygen appears to play an important part in the process.

Calculations based on our laboratory experiments indicated that the effective life of the Katadyn sand in practice would be short, and the cost of the treatment therefore high compared with other methods of sterilisation, such as chlorination. Also, owing to the progressive deterioration of the sand, constant supervision, regulation of the plant and bacteriological control would be required.

The introduction of the metal into water by the passage of an

electric current has been introduced as an advance on the sand method, but in view of the superiority of other methods of water sterilisation we do not consider either will find a place in waterworks practice. The

TABLE I

RATE OF FILTRATION : RAPID, *i.e.*, CORRESPONDING TO ABOUT
100 GALLONS PER SQUARE FOOT PER HOUR

Nature of Water. Rough Filtered to remove Suspended Matter when present.	No. of Bacteria growing per c.c. on		Coliform Count on McConkey's Agar.	Bact. Coli. as isolated from Liquid Media.
	Agar at 37° C. in 1 day.	Gelatin at 20° C. in 3 days.		
1. Lake water of low grade organic purity, RAW .	3,400	300,000	60	+ 0.01 c.c. - 0.001 c.c.
2 hr. after filtration . .	15	150	0	+ 1 c.c. - 0.1 c.c.
4 hr. after filtration . .	8	70	0	+ 20 c.c. - 10 c.c.
6 hr. after filtration . .	3	52	0	- 100 c.c.
2. Chalk water of good organic quality, RAW	3,200	50,000	5	+ 0.1 c.c. - 0.01 c.c.
2 hr. after filtration . .	2	820	0	+ 20 c.c. - 10 c.c.
4 hr. after filtration . .	2	84	0	- 100 c.c.
6 hr. after filtration . .	0	42	0	- 100 c.c.
3. Chalk water of good organic quality, RAW	78	2,400	3	+ 0.1 c.c. - 0.01 c.c.
2 hr. after filtration . .	4	25	0	- 100 c.c.
4 hr. after filtration . .	2	14	0	- 100 c.c.
4. Greensand water of good organic quality, RAW	96	640	0	+ 5 c.c. - 1 c.c.
1 hr. after filtration . .	4	41	0	- 100 c.c.
2 hr. after filtration . .	0	28	0	- 100 c.c.
5. Shallow well water, poor organic quality, RAW	95	—	0	+ 5 c.c. - 1 c.c.
2 hr. after filtration . .	33	—	0	+ 5 c.c. - 1 c.c.
4 hr. after filtration . .	4	—	0	+ 50 c.c. - 10 c.c.
6 hr. after filtration . .	1	—	0	- 100 c.c.

dosage of silver is controllable by the electric method since 1 ampere of current per hour introduces 4.023 mgms. of silver into the water. In the treatment of swimming bath waters, doses of 0.01 to 0.02 parts

per 100,000 of silver are used but in the one instance of our experience the process was not successful.

Table I shows a few examples of the results obtained by filtration of polluted water through Katadyn sand.

References

- DELEPINE and GREENWOOD. 1914. *Journal Roy. San. Inst.*, XXXV., 6.
KRONIG and PAUL. 1897. Quoted from "Principles of Bacteriology and Immunity," by Topley and Wilson, 1938.
MORGANS. 1935. Paper No. 13. Public Works, Road and Transport Congress, London.
SUCKLING. 1931. *Water and Water Engineering*, Vol. XXXIII., December, 1931.
WHITSON. 1940. *The Surveyor*, March 22nd.
WILSON. 1922. *Journal of Bacteriology*, VII., 405.

CHAPTER XLI

THE BACTERIAL PURIFICATION OF WATER BY CHLORINATION

THE deodorising and disinfectant properties of chlorine and chlorine compounds have been known for many years, and "Eau de Javelles" (a solution of potassium hypochlorite) has been in use in France since 1792.

The first applications of chlorine in sanitary science were to sewage rather than to water, and chlorination still finds a place in sewage treatment.

In 1897, Sims Woodhead was responsible for the first practical application of chlorination to public water supplies in England. As an emergency measure, following an outbreak of typhoid fever at Maidstone, the public water supply was treated with bleaching powder. Also, during an epidemic of typhoid fever at Lincoln in 1905, and for several years afterwards, Houston and McGowan used chlorine in the form of sodium hypochlorite solution for the sterilisation of the public water supply.

In 1906, the purity of the water supply to Cambridge came under suspicion, and, as a result of investigations and experiments carried out by Hehner, Houston, Thresh and Sims Woodhead, a unanimous recommendation to safeguard the purity of the supply by chlorination was made to the Water Authority. The proposal was not, however, put into effect since it did not receive Parliamentary approval.

In 1908, an article was contributed to the *Lancet*, entitled "The Sterilisation of Potable Waters by Means of Calcium Hypochlorite" (Thresh, 1908), and it concluded thus: "Assuming that on the large scale the same results can be obtained as in the laboratory—and there appears to be no reason why such should not be the case—the adoption of such a method of water purification may result in an enormous saving in capital expenditure and very greatly reduce the risk of water-borne epidemics."

The water engineer of Reading (Mr. Leslie Walker) thereupon investigated this matter, and, in collaboration with the Candy Filter Company, installed, under our supervision, an experimental chlorinating and dechlorinating plant, the latter consisting of filtration of the treated water through a bed of carbon. The results obtained were so satisfactory that in 1910 the Corporation installed full-scale plant for the treatment of the public water supply. Reading Corporation thus became the first water authority in this country to adopt chlorination as a routine measure.

Various deputations, including one from the Army Medical Advisory Board and one from the Metropolitan Water Board, visited the Reading Waterworks. The representative of the Metropolitan Water Board wrote in the visitors' book on April 21st, 1911: "I inspected the pre-filtration and de-chlor system at Reading. After full examination, I was struck by the simplicity, regularity and cheapness of the process. On appeal to the senses the finished water was found to be bright and clear, and without odour or taste. Mr. Walker and the Reading Corporation are to be congratulated on their foresight and boldness."

Acting on our advice, a number of water authorities quickly followed Reading in installing chlorination as routine treatment, amongst these being the Truro Water Company in 1911, and the South West Suburban Water Company in 1912.

Large-scale chlorination of water supplies began in America about the same time as in England and its expansion was rapid. By 1925 over 75 per cent. of the municipal supplies of North America were chlorinated, and in 1942 it is estimated that 85 per cent. are so treated.

Although the utility of carbon as a dechlorinating agent has long been known and was confirmed by its practical application at Reading more than thirty years ago, any extension of its use in waterworks' practice has become noticeable only within the last few years. This is probably due to the production of improved forms of carbon known as activated carbon.

The War of 1914-1918 greatly expanded the practice of chlorination, and it was generally adopted by the British Armies in the field for the treatment of all water supplies. During that period, it was also adopted by the Metropolitan Water Board for the treatment of part of London's water supply.

Expansion of the process has been rapid in recent years, and it is now employed in all parts of the world. In England there are few public water supplies of any magnitude in which chlorination is not normally employed in one form or another, and, as a war-time precautionary measure, its application is general.

There is no question of doubt that chlorination has been one of the greatest advances in water purification. It has proved of inestimable value to water authorities and has permitted the utilisation of many supplies which otherwise would not have attained the required standard of purity.

In addition to the extra security which chlorination provides against water-borne disease, the process has also effected much economic advantage, as it is inexpensive, and obviates, wholly or in part, the necessity for raw water storage. Chlorination accomplishes greater bacterial purification in minutes than storage achieves in an equal number of days, and the construction of reservoirs of the required capacity is very costly. Also, slow sand filtration was previously employed for the bacterial purification of water, in addition to the removal of suspended matter. Bacteria are removed only by a very slow rate of filtration and even then results may not be fully satis-

factory at all times of the year. Chlorination provides, therefore, a convenient accessory to filtration.

Water purification by storage and slow sand filtration has been widely carried out for many years in this country with great benefit in the prevention of water-borne disease. In other parts where similar precautions were less frequent, and typhoid fever more prevalent, the reduction in the incidence of the disease, subsequent to the introduction of chlorination, has been striking.

The efficiency of chlorination in preventing the known water-borne bacterial diseases is open to no doubt, but it is essential to obey certain rules in its application, otherwise failures occur. The haphazard, uncontrolled addition of chlorine to water is not chlorination, is dangerous in creating a false sense of security and is responsible for many of the complaints and criticisms of the process. It is essential that the water to be treated should be in suitable condition, that the chlorine should be properly applied in respect of method and dosage, that the contact time should be adequate, and the control conscientious and efficient. These various conditions will be described in greater detail in later paragraphs.

Chlorine and Hypochlorites. Chlorides of hydrogen, potassium or sodium, particularly sodium chloride (common salt), provide the raw material from which chlorine is produced. Chemical or electrolytic methods of production can be employed, but the latter are now commercially by far the more important. The principal chemical methods still in use on a small scale consist briefly in the oxidation of hydrochloric acid. In one process (Weldon), manganese dioxide is used according to the equation: $\text{MnO}_2 + 4\text{HCl} = \text{Cl}_2 + \text{MnCl}_2 + 2\text{H}_2\text{O}$. This method is less worked than Deacon's process which fundamentally consists in passing a mixture of hydrochloric acid gas and air, at a temperature of 370° to 400°C. , over pumice or clay balls saturated with cupric chloride solution. Under these conditions, the hydrochloric acid is oxidised by the atmospheric oxygen, according to the equation: $4\text{HCl} + \text{O}_2 = 2\text{Cl}_2 + 2\text{H}_2\text{O}$, but there are secondary or intermediate reactions in which the copper salts take part.

Common salt is now the most important source of chlorine, and the method of production consists of the electrolysis of brine. In simple form this can be represented by the equation: $2\text{NaCl} = 2\text{Na} + \text{Cl}_2$, but there are various secondary reactions, and special electrolytic cells and methods must be used to obtain a yield of chlorine.

Chlorine, discovered by Scheele in 1774, was first thought by the chemists of that time to be a compound, but in 1810, Davy established it as an element and gave it its present name. Chlorine gas has a greenish-yellow colour, a pungent odour, causes irritation when inhaled, and, if present in the atmosphere in more than the minutest traces, gives rise to serious damage to lungs and other tissues, which may result in death. Severe coughing will be caused by the presence of 1 volume of the gas in 10,000 volumes of air. Represented by the symbol Cl, it has atomic weight 35.46 and is 2.49 times as heavy as air. Chlorine is soluble in water to the extent of 4.61 volumes in 1 volume at 0°C. and 2.26 volumes at 20°C. , and the solution is called chlorine-water. At low temperatures, crystals consisting of a hydrate of chlorine ($\text{Cl}_2 \cdot 8\text{H}_2\text{O}$) form in the chlorine water. This sometimes occurs in water chlorinating plants and causes blocking of jets and fine tubes. Crystal formation may also be responsible for the development of odour and taste which occasionally arises unexpectedly in chlorinated water in very cold weather.

Chlorine-water is not stable, and decomposition is particularly rapid on exposure to sunlight. It is probable that the first products are hydrochloric and hypochlorous acids and the final products hydrochloric acid and oxygen according to the equations: (a) $\text{Cl}_2 + \text{H}_2\text{O} = \text{HCl} + \text{HOCl}$, (b) $2\text{HOCl} = 2\text{HCl} + \text{O}_2$.

Chlorine, although non-combustible, is a supporter of combustion. In the presence of moisture it is very active chemically, being a powerful oxidising and bleaching agent, and very corrosive to metals.

Chlorine can be condensed under pressure to an amber-coloured, oily liquid which is about one and a half times as heavy as water. Liquid chlorine is supplied for the chlorination of water and is transported and stored in pressure cylinders or drums. Cylinders containing 70 lbs. of chlorine are commonly used, drums containing up to a ton of chlorine being supplied only to exceptionally large waterworks. The cylinders must be handled with care and not stored or placed where temperature increases may occur, such as near fireplaces or radiators. In use, the cylinders are connected to adjusting and dosing apparatus which deliver the released chlorine gas to the water in regular, predetermined and controlled amount. There may be a direct gas feed to the water, but more often the chlorine is added to a minor flow of water and this strong solution is then uniformly mixed with the main bulk of water to be treated. The apparatus as a whole should be kept at comfortable room temperature (60° to 70° F.) since irregularities arise from cold, and the gas must not be withdrawn too quickly (not more than $1\frac{1}{2}$ lbs. per hour) from the cylinders, otherwise the internal temperature is unduly lowered. Good ventilation should be provided to the rooms housing the chlorination plant; the attendants should be instructed and experienced, and masks should be available in the event of emergency, such as the occurrence of leaks requiring repairs.

Hypochlorites are used in water chlorination, particularly in small-scale and emergency practice. They are salts of hypochlorous acid, and, like the acid, are unstable when pure, and are used, therefore, in an impure form. Decomposition of hypochlorites is accelerated by the presence of acids and delayed by alkalis. Therefore, stabilisation is obtained by admixture with excess alkali, and hypochlorites are more active in sterilising acid waters than those which are alkaline. The commonest hypochlorite preparations used in water chlorination are sodium hypochlorite solutions and "chloride of lime" or "bleaching powder." Both are produced by chemical methods, but comparatively weak hypochlorite solutions (1 per cent. available chlorine) can be prepared by the electrolysis of common salt, suitably arranged cells and operation causing the chlorine to react with the caustic soda formed by the action of sodium on water.

Such commercial preparations as "Chlor-San" and "Milton" are stabilised hypochlorite solutions (1 per cent. available chlorine) of this character, and they can be used for small-scale, domestic, emergency sterilisation of water.

Chemically, sodium hypochlorite solutions are made by passing chlorine into a solution of caustic soda. The reaction can be represented by the equation: $2\text{NaOH} + \text{Cl}_2 = \text{NaOCl} + \text{NaCl} + \text{H}_2\text{O}$. Sufficient excess of alkali is retained to give the solutions a pH value of approximately 11, thus improving stability. Commercial preparations of this character, such as "Chloros," "Voxsan," "Hychlor," "Conchlor," etc., have strengths,

expressed in terms of the available chlorine contents of 10 to 15 per cent. W/V. The solutions keep reasonably well for a limited time on careful storage in sealed containers in a dry, cool place. In one series of observations we found the available chlorine fell by 25 per cent. in six months and 50 per cent. in twelve months.

These hypochlorite solutions, being caustic and corrosive, should be handled with care, and splashing in the eyes may cause serious injury.

Chlorinated soda (Liquor Sodæ Chlorinatæ, B.P.) is prepared by mixing 4 parts of bleaching powder in 30 parts of distilled water with 6 parts of sodium carbonate in 10 parts of distilled water, and filtering. If the bleaching powder contains 33 per cent. available chlorine, the chlorinated soda solution contains 2.7 per cent. available chlorine. Stored in a sealed, coloured glass bottle in a cool, dark place, the solution keeps reasonably well for several months.

Bleaching powder is produced by the action of chlorine on slaked lime. The reaction can be represented by the equation: $\text{Ca(OH)}_2 + \text{Cl}_2 = \text{Ca(OCI)Cl} + \text{H}_2\text{O}$. This reaction is not completed in practice and about 50 per cent. of lime remains free in the final product, and bleaching powder was, therefore, represented as: $2\text{Ca(OCI)Cl} + \text{Ca(OH)}_2$. It has been shown, however, that bleaching powder is a mixture of a basic chloride: $\text{CaCl}_2 \cdot \text{Ca(OH)}_2 \cdot \text{H}_2\text{O}$ and a basic hypochlorite: $\text{Ca(OCI)}_2 \cdot 2[\text{Ca(OH)}_2]$ in approximately molecular proportions. The available chlorine is usually 35 per cent. and the presence of an excess of lime improves the stability of the product.

Bleaching powder, particularly when stabilised, maintains its strength when packed in sealed containers and stored in a cool, dark, dry place. On exposure to air, light and moisture, chlorine is rapidly lost. Hypochlorites are so unstable that they are decomposed by feeble acids, and by the carbon dioxide of the atmosphere.

In water sterilisation, bleaching powder is rubbed into a suspension with a small quantity of water, the solids allowed to settle, and the clear supernatant solution then added to the water to be treated. Since the lime sludge retains a portion of the chlorine, it is advisable to allow 10 per cent. for this loss in calculating the requirements. The process is inconvenient and is practically confined to emergency treatment.

In the U.S.A. stable hypochlorites, containing approximately 70 per cent. available chlorine, are now produced commercially.

Factors Influencing Sterilisation of Water by Chlorine

There are several important factors concerned with the successful chlorination of water, and each water supply should be individually considered in respect of the character of the water and the method of chlorination best suited to the circumstances of the waterworks. It is impossible to standardise chlorine dosage, plant and method to suit all cases, and, whenever the construction of new waterworks is under consideration, it is advisable to make provision that chlorination can be installed, if and when required, in the most efficient, reliable, and economical manner. There are no instances in which it can be accepted that chlorination will never be required. The addition of chlorination to existing waterworks has often necessitated considerable constructional alterations, and, in some cases, the installation of a really reliable and efficient scheme has proved impracticable.

Chlorine does not destroy all bacteria, but, given suitable conditions, it is a powerful and reliable germicide in respect of the bacteria of water-borne diseases. The bacteria must be exposed to a sufficient concentration of chlorine for an adequate period of time (contact time).

Water, being consumed unheated, can be regarded as a raw food and it should, therefore, be produced and delivered to the consumers with every possible precaution against bacterial contamination. In view of the possibilities of pollution, sometimes admittedly only very remote, routine chlorination of all public water supplies has been suggested, but the proposal aroused widespread objections.

Condition of Water. The water to be chlorinated should be reasonably clear and bright, or rendered so by filtration or other means. The presence of suspended matter impedes chlorination by absorbing chlorine and by protecting bacteria. The latter may be embedded in the particles and remain out of contact with any chlorine, thus escaping destruction.

Certain impurities of water, such as organic matter, sulphides, nitrites and iron, absorb or destroy chlorine, and their demands must be satisfied before any chlorine is available for germicidal action. The presence of free and saline ammonia is also of importance, since more than insignificant traces cause considerable retardation of sterilisation. Chemical analyses are, therefore, of great value when chlorination is under consideration. Also, suitable preparation of the water may be essential before chlorine can be properly, reliably and efficiently applied.

Temperature. Temperature has a noticeable effect on chlorination, cold causing delay, both in germicidal action and in the absorption of chlorine. Residual reactions usually persist longer in winter than in summer, but secondary factors, such as biological activity in reservoirs and mains, often play a part in this effect.

Reaction. The pH value of water influences chlorination, sterilisation being more rapid in acid than in alkaline waters. With high pH, residual reactions are maintained longer, thus compensating for the slower action, assuming adequate contact time is provided.

The effects of temperature and alkalinity are more noticeable in waters containing ammonia, or to which ammonia has been added.

Dosage and Contact Time. The concentration of chlorine is obviously of the greatest importance. It must be sufficient to satisfy the demand of the water and to destroy bacteria, yet not so high as to render the water odorous and unpalatable, unless dechlorination is also employed. An efficiently chlorinated water is one which has been adequately sterilised and rendered safe and agreeable to drink. The presence of odour and taste is objectionable to consumers and involves the risk that resort may be made to other sources yielding polluted, though palatable, waters. The required dosage for any water is that amount of chlorine which, after satisfying the immediate demands of the impurities in the water, leaves a sufficient residuum to destroy the bacteria. Since this destruction is not instantaneous an adequate contact time must be allowed. Dosage and contact time are, therefore, closely related, there being a broad inverse correlation between the residual chlorine and the time period in which sterilisation is achieved. Residual chlorine refers to that chlorine which is left after the demand of the water has been satisfied.

Under most circumstances, sufficient residual chlorine to be effective in a short contact time is advisable. The chlorinated water can then be retained at the waterworks in a "contact" tank, and the maintenance of the chlorine throughout the required period confirmed before release of the water to the distribution mains. The procedure of adding a small dose of chlorine to water being passed directly into distribution without adequate contact time, or facilities to confirm the residual chlorine reaction, is unsatisfactory. In some cases where the water is retained in service reservoirs before delivery to the consumers, long contact time is available, and ammonia-chlorine treatment (see p. 644) is then often employed. Since the appropriate chlorine dose depends on the quality of the water, the content of ammonia, and the contact time available, each case must be individually considered. Helpful information can be obtained from the chemical analyses of the water, together with laboratory determinations of chlorine absorption. The adequacy of the dosage decided should then be regularly confirmed in practice by tests for the residual chlorine reaction at the end of the allotted contact period, together with bacteriological examinations of the final water.

There are several different methods of chlorination in which appropriate chlorine doses and contact times vary, but as a general rule the doses administered to public supply waters vary from 0.15 to 1.0 part per million. With clear and bright waters of great organic purity, such as some of those derived from deep wells or boreholes in the Chalk, Greensand, Sandstone, etc., it is found that the chlorine demand is so small that a dose of 0.1 part per million suffices to leave a residuum after thirty minutes' contact and to achieve satisfactory sterilisation. In other cases, waters from underground sources may be of good organic purity yet contain some chlorine absorbing matter such as iron, manganese or sulphuretted hydrogen, and require 0.25 to 0.5 part per million of chlorine to give an effective residuum. Efficiently treated surface waters, such as those from rivers and impounding reservoirs, are usually satisfactorily chlorinated with doses of approximately 0.5 part per million. Higher doses of 1.0, or even 2.0 parts per million are required when purification, *i.e.*, the removal of suspended matter, organic and colouring matter, is less efficient.

As a general rule, water which is clear and bright in appearance and has been so chlorinated that 0.1 part per million of free chlorine remains at the end of thirty minutes' contact, will be bacteriologically satisfactory. This may not be the case if the temperature is low and the pH value of the water high, or ammonia is present in undue amount. Under these various conditions, higher doses of chlorine and longer contact periods are required.

The contact time required for waters containing appreciable traces of free ammonia is usually between one and four hours, but may be longer if the ratio of ammonia to chlorine exceeds 1 : 1, the temperature is low, the alkalinity of the water is high, or its organic impurity considerable.

It is emphasised that no conditions of dosage and contact should be accepted unless their full adequacy is confirmed by bacteriological examinations of the treated water.

With careful preliminary investigation and subsequent confirmatory tests, it is usually readily practicable to arrange optimum conditions for chlorination, with a margin of safety, and without unduly affecting the palatability of the water. Difficulties arise chiefly at older waterworks constructed before the development of chlorination.

Chlorination is usually applied as a final or finishing process, but it is sometimes employed otherwise, *e.g.*, as a preliminary treatment of raw, impure water, when doses and contact times differ from the above.

Applications of Chlorination to Water Supplies. When used as a final process, chlorination should be regarded as an additional safeguard to public water supplies, and not as the treatment on which the bacterial purity of the water solely depends. It should, therefore, be applied to waters which, naturally or as a result of treatment, are clear and bright and of good quality. In normal practice, chlorination may permit modification of waterworks' design, but it does not permit the omission of filters or the inefficient purification of impure waters containing suspended matter or appreciable organic matter.

In many cases, underground sources yield clear waters of satisfactory organic and bacterial purity, suitable, without treatment, for drinking and domestic purposes. Chlorination is, however, often applied in such cases as a precautionary measure, particularly in supplies obtained from fissured strata, such as the Chalk and Limestone. The occasional appearance of a few *Bact. coli*, such as after heavy rainfall, may be the only indication of danger, the clarity and organic purity of the water remaining unimpaired. The remote possibility of pollution is always present in spite of careful location and construction of the wells and the application of all practicable pollution-prevention measures. With increasing population, industry and building developments, encroachment on gathering grounds extends and magnifies the risks to many underground water supplies. Carefully controlled chlorination is a valuable safeguard and is being increasingly used in such cases.

Chlorination is sometimes employed as a pre-treatment measure, raw water receiving a comparatively high dose prior to coagulation, settlement and filtration, followed by a further small chlorine dose after filtration. In pre-treatment, the dose is usually arranged so that after as long a contact time as possible a residual reaction of the order of 0.2 part per million remains in the water passing on to the filters. This measure provides an additional bacterial safeguard, restrains algal growths in tanks, and on slow sand beds, if used, and may assist coagulation and settlement of solids prior to rapid sand filtration of the water. Ammonia-chlorine treatment of raw water may be preferable when the retention before filtration is very long; when there is a risk of chlorophenol odours, and assistance in decolorisation and coagulation of the water is not required. Chloramines do not oxidise so well as chlorine.

In water-softening plants, chlorination is often employed either as pre-treatment or as a final process. Chlorine can be added prior to the lime in lime-softening plants, and residual chlorine readily maintained throughout the settlement tanks, particularly when these are covered, thus obtaining long contact. It can similarly be added prior to base-exchange softening, and residual reactions of the order of 0.2 part per million are not detrimental to zeolites. Water-softening zeolites of the siliceous type do not dechlorinate.

When considering the point of application of chlorine, the advantages of obtaining a long contact period should always be kept in mind, and, generally, the longer the chlorinated water is held under observation at the treatment works, the greater is the security obtained.

Chlorination is sometimes advantageously included in iron-removing plants, since, in addition to its germicidal action, it facilitates oxidation and precipitation of iron.

Methods of Chlorination. There are three common chlorination methods, *i.e.*, simple chlorination, chlorination and dechlorination, and ammonia-chlorine (chloramine) treatment.

In large supplies, cylinders of liquid chlorine with "gas-chlorine" apparatus are employed, but, in small supplies, and when the pumping rate is less than 2,000 gallons per hour, sodium hypochlorite solution dosing apparatus are usually more suitable.

An apparatus is manufactured by which sodium hypochlorite solution can be prepared in the treatment plant and injected directly into the water. The process consists of the electrolysis of a 10 to 15 per cent. solution of common salt, and, with suitable conditions of electric current and temperature, a sodium hypochlorite solution containing approximately 1 per cent. available chlorine is obtained. Salt, electricity and replacement of electrodes constitute the main items of cost, and the process is practicable at certain small installations and at some waterworks. It might, for example, be applicable with advantage at works having base-exchange softening plant, where a supply of salt is already available. With suitable modification of the apparatus, the process is employed on ships, when sea water can be used as the raw material instead of brine. A reserve of the sodium hypochlorite solution, partially stabilised by the addition of sodium hydroxide, can be stored for short periods for use in the event of temporary break-down of the electric current supply.

Simple Chlorination. This consists merely of the addition to water of chlorine in regular, controlled dose. It is frequently applied purely as a precautionary measure to supplies of satisfactory purity, and the dose is usually small. The residual chlorine may disappear during storage in service reservoirs or passage through the distribution mains, or, when the contact is not prolonged, be retained in the water delivered to consumers. This method has the disadvantages that usually only small doses can be given, thus lessening security; chlor-phenol odours may be produced, and many consumers complain of chlorinous odour even with such small residual chlorine reactions as 0.05 to 0.1 part per million.

Chlorination and Dechlorination. In most cases, chlorination,

followed by dechlorination after an appropriate contact period, is the best method for public water supplies. The method has great flexibility, affords a maximum degree of security, and gives least offence to the consumers. The dose of chlorine applied is much greater than that of simple chlorination and, accordingly, the destruction of bacteria is more rapid. Only short contact is, therefore, required and this is often of great convenience at waterworks unprovided with clear water tanks or service reservoirs. The dose of chlorine administered varies according to the circumstances of the waterworks, the character of the water, etc., but it is usually four to five times that of simple chlorination, and there is, of course, much more residual chlorine present after a given contact period. The method is therefore often referred to as "superchlorination," since the dose has been greater than necessary to disinfect the water, and there remains an excess of chlorine sufficient to be decidedly objectionable to consumers. A superchlorination dose for one water may be an ordinary dose for another. For example, a very pure water from an underground source chlorinated with 0.1 part per million may be adequately sterilised and retain residual chlorine of 0.08 part per million after thirty minutes' contact, and give rise to complaints from consumers of chlorinous odour. A dose of 0.5 part per million would be a superchlorination dose in such a case, since approximately 0.4 part per million (rendering the water distinctly chlorinous in odour) would remain after thirty minutes' contact, and its diminution would be slow, thus necessitating dechlorination. On the other hand, 0.5 part per million of chlorine is quite an ordinary dose for many supplies, and some filtered supplies of surface origin require even double that dose to give a residual reaction after thirty minutes' contact, in which case 5 parts per million would represent a 'superchlorination dose. Superchlorination, probably on account of its greater oxidising action, often prevents complaints of odour and taste in the treated water, and further reference to this matter is made in a later section under the heading of "break-point" chlorination. Superchlorination is sometimes applied to impure waters as a pre-filtration treatment, for the purposes of destroying bacteria and minimising the final chlorine dose after filtration, and also to restrain the development of odour and taste. The latter is effected by oxidising or breaking down substances which cause odour and taste when combined with small traces of chlorine.

When applied as a final treatment, superchlorination requires only a short contact period of five to fifteen minutes according to the magnitude of the dose and its residuum. The system is, therefore, conveniently arranged so that the chlorine is administered at the inlet to a small, covered, baffled contact tank, and dechlorination takes place at the outlet. In some cases, a "loop" main is constructed round the waterworks, through which the water flows before passing into distribution, and in which contact of about fifteen minutes can be obtained. The water is chlorinated at one end of the loop and dechlorinated at the other, and the points can be adjacent to permit the two plants to be conveniently housed together and kept under observation. Sampling

taps should be appropriately installed so that the water can be regularly tested before and after dechlorination.

Dechlorination. Excess of chlorine remaining in the treated water can be removed by the addition of chemicals, such as sulphur dioxide, sodium thiosulphate, and sodium hyposulphite, or by filtration through a bed of activated carbon. Coke and charcoal filters have been used but are less satisfactory. Exposure to air and sunshine will destroy free chlorine, but this is not a practical or desirable measure for final waters intended for public supply purposes.

Sulphur dioxide is the commonest dechlorinating agent used in large supplies and sodium thiosulphate in small supplies. Carbon dechlorination is used less often, but there are several medium sized and small supplies in this country in which it is successfully employed.

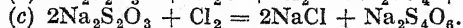
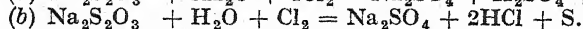
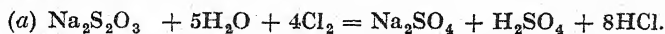
Sulphur Dioxide, SO_2 , is formed when sulphur burns in air ($\text{S} + \text{O}_2 = \text{SO}_2$) or certain sulphides, such as iron pyrites, are strongly heated in air: $4\text{FeS}_2 + 11\text{O}_2 = 2\text{Fe}_2\text{O}_3 + 8\text{SO}_2$. It is a colourless, poisonous gas with an odour of burning sulphur, incombustible and a non-supporter of combustion. Sulphur dioxide is soluble in water to the extent of approximately 39 volumes in 1 volume of water at 20°C ., and 80 volumes at 0°C . The solution (sulphurous acid, H_2SO_3) is unstable and decomposes on exposure to light, forming sulphuric acid and sulphur: $3\text{H}_2\text{SO}_3 = 2\text{H}_2\text{SO}_4 + \text{S} + \text{H}_2\text{O}$. Sulphur dioxide is a strong reducing agent and its action in destroying chlorine in water can be represented by: $\text{Cl}_2 + \text{SO}_2 + 2\text{H}_2\text{O} = 2\text{HCl} + \text{H}_2\text{SO}_4$. The minute traces of acid produced are neutralised by the alkalinity of the water.

Condensation of sulphur dioxide is readily carried out, the gas liquefying under ordinary pressures at -10°C . and at a pressure of $1\frac{1}{2}$ atmospheres at 0°C . It is supplied to waterworks in the liquid form, contained in pressure cylinders. When in use the release of gas reduces the temperature of the cylinder and the plant must therefore be housed in a warm atmosphere in order to obtain satisfactory working. The operating plant is similar in design to that used in connection with cylinders of liquid chlorine.

Dechlorination of water is effected by 0.9 part per million of sulphur dioxide for each 1 part per million of chlorine or chloramine. When complete dechlorination is desired a 1:1 ratio (sulphur dioxide: residual chlorine) can conveniently be employed, but with waters of low chlorine absorption the sulphur dioxide dose is often fixed at the same level as the chlorine dose, thus leaving ample excess to ensure complete dechlorination. In other instances the dose is so adjusted that dechlorination is partial and a trace of residual chlorine remains in the water pumped to service reservoirs and distribution mains. The dechlorinating reaction is very rapid and no retention of water in a "reaction" tank is required. The sulphur dioxide is harmless in the doses employed and causes no change in the appearance, wholesomeness or corrosive action of the water. An excess is, however, undesirable, as it may encourage certain bacterial after-growths.

Sodium Thiosulphate, $\text{Na}_2\text{S}_2\text{O}_3$, is the commonest salt of thiosulphuric acid, and is used by photographers under the name of "hypo." It is a crystalline solid ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$), very soluble in water and a convenient dechlorinating agent. A solution of known strength is made and apportioned at a pre-determined rate to the chlorinated water by ordinary solution feed apparatus.

The reaction between the chlorine and thiosulphate may be represented by the equations :—



Using the common "hypo," $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$, there are required theoretically for 1 part of chlorine 0.9 part of sodium thiosulphate according to reaction (a), 3.5 parts in (b) and 7 parts in reaction (c). We have found, however, that none of these reactions applies in practice. Under the conditions of extreme dilution occurring in the dechlorination of water, the required ratio of "hypo" to chlorine varies with different waters, but is generally intermediate between those of reactions (a) and (b).

In laboratory experiments, taking no strict precautions with regard to temperature, access of light, etc., we determined a mean ratio of "hypo," $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$, to chlorine of 2:1. This ratio may sometimes be lower in practice, and at an installation where a Chalk-derived water is lightly chlorinated (residual chlorine reaction 0.25 p.p.m.), a long series of tests showed that a ratio of 1.8:1 sufficed for dechlorination.

Sodium hyposulphite, $\text{Na}_2\text{S}_2\text{O}_4$, is used industrially, and in the laboratory, as a reducing agent, but it is employed less often than the thiosulphate for dechlorinating water.

Activated Carbon. Carbon dechlorinates water by the process of adsorption. The carbon, in granular form, is contained in units resembling rapid sand filters, and, since the action is very rapid, a high rate of filtration can be employed. The carbon must be periodically replaced, or reactivated by steam and air, but the "runs" are sufficiently long for the process to be practicable. Carbon filters should not be allowed to stand idle for long periods, otherwise biological growths become established, particularly in hot weather, and numerous bacteria of non-pathogenic types are added to the dechlorinated water. The filters should be fitted with wash-outs so that they can be cleaned occasionally, and the availability of a "bye-pass" main, whereby a fraction of the superchlorinated water can be mixed with the filtered fraction, permits partial dechlorination.

Instead of a granular carbon filter bed, powdered activated carbon can be added to the chlorinated water which is then filtered by ordinary rapid sand filters. The carbon is removed on the sand filters and lost when these are backwashed. This method is less satisfactory than filtration through a bed of granular carbon.

In addition to dechlorinating, activated carbon is helpful in removing odour, taste and colour from water, and, when processes of cleansing and reactivation are improved, it should find increasing favour in water purification plants.

"Break-Point" Chlorination. It has been noted that certain earthy, musty odours and tastes in water could be destroyed by chlorination at higher doses than was necessary for bacteriological purposes. The first effect of higher chlorine dosage may be to accentuate these odours, after which they disappear with more chlorine and are replaced by a definite chlorinous odour which is removable by ordinary dechlorination methods. American workers have shown that on the addition of increasing chlorine to some

impure waters, the residuum progressively rises up to a certain point when it falls, even to zero, and then steadily rises again in proportion to the dose. The point of fall has been called the "break-point" and it occurs when odour-producing organic matter is oxidised. Colour due to organic matter is also reduced. It appears therefore that up to a certain concentration of chlorine, organic matter combines with chlorine and is rendered more odorous, but it is sometimes within the range of practical chlorination to break down the organic matter and prevent the objectionable earthy, musty odours and tastes which are usually not removed by filtration. An example of the "break-point" effect is given by a water which, when dosed with 2.0 p.p.m. of chlorine, had a residual reaction of 0.8 p.p.m. after two hours' contact, but with chlorine doses of 4, 6, 8, 9 and 10 p.p.m. the residual figures after two hours' contact were 1.5, 2.7, 1.3, 0.3 and 0.5 p.p.m. respectively. The "break-point" occurred therefore at approximately 6 p.p.m., after which concentration, chlorine was expended in oxidising organic matter and the residual readings fell. The "flash-reading" method of residual chlorine testing by ortho-tolidine solution was developed in America for the control of "break-point" chlorination. (See paragraph under heading "Control of Chlorination—the Ortho-Tolidine Method," p. 649.) The concentration of chlorine at which the "break-point" occurs varies in different waters and may be under 1 p.p.m., or well over 10 p.p.m., whilst in many cases it cannot be discerned at all. It is not constant on the same water supply, varying according to the character of the water, particularly in respect of its nitrogenous content, and the temperature. Chlorination to beyond the "break-point" may, however, provide the means of obtaining satisfactory treatment results in certain waters which are difficult to deal with by ordinary methods, such as normal chlorination and filtration, but careful consideration and experiments are necessary in each individual case.

In view of these developments the meaning of the word "superchlorination" is more confused than ever. It was previously applied when the chlorine dose was more than sufficient to destroy bacteria, or when a quick sterilising action was required, and was followed by dechlorination. It might now refer to chlorination in excess of the "break-point" dose, when dechlorination is not necessarily required.

Ammonia-Chlorine (Chloramine) Treatment. Chloramines may be formed when water naturally containing ammonia is chlorinated or when ammonia is deliberately administered in addition to chlorine. Chloramines are less active oxidising and germicidal agents than chlorine but they are more stable, and hence an active residuum remains for a much longer period (several days) in the treated water. This is an advantage where the water is retained for long periods in reservoirs and mains before delivery to the consumers, since a high standard of bacterial purity can be preserved and after-growth of bacteria prevented. Also, the presence of ammonia exerts a restraining influence on the development of "chlor-phenol" odours in chlorinated waters.

Rideal (1910) noted the stabilising effect of ammonia in the chlorination of sewage and also found that the phenol coefficient of hypochlorite solution (1 per cent. available chlorine) was raised from 2.18 to 6.36 by the addition of an equivalent of ammonia.

Race (1918) was the first to apply ammonia-chlorine to public water supplies. He developed the process at Ottawa in 1914-17 and recorded the following results:—

1. 0.2 p.p.m. of chlorine and 0.1 p.p.m. of ammonia gave equally

as good bacteriological results as 0.6 p.p.m. of chlorine without ammonia.

2. The absorption of chlorine by the organic matter present in the water was largely prevented by ammonia and after twenty hours there was a residue of 67 to 96 per cent., depending on the ratio of chlorine to ammonia.

3. An adequate contact time is important and the contact period must be increased as the concentration of chloramine is decreased.

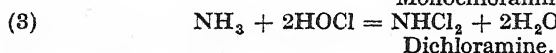
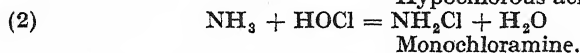
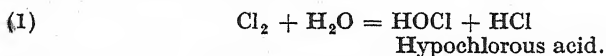
4. After-growths of bacteria, noted during the use of chlorine alone, were entirely eliminated by chloramine treatment. Bacteriological results of samples collected at distant points of the distribution system were far superior.

5. Since the introduction of the process in Ottawa no complaints of odour and taste have been received.

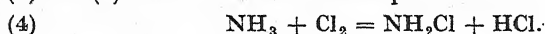
Race's findings were confirmed by workers in this country and America, since when the process has been widely used for the treatment of public water supplies.

Chemistry of Chloramine Treatment. Ammonia can be added to the water under treatment either as the gas, NH_3 , an aqueous solution of ammonia ($\text{NH}_3 + \text{H}_2\text{O} = \text{NH}_4\text{OH}$) or as an ammonium salt, usually the sulphate [$(\text{NH}_4)_2\text{SO}_4$].

The reactions taking place in the water between chlorine and ammonia can be represented as follows:—



(1) and (2) can be combined and expressed as:—



Since the "available chlorine" content of the chloramine in (4) is double the chlorine contained in the molecule, *i.e.*, it liberates two atoms of iodine from hydriodic acid ($\text{NH}_2\text{Cl} + 2\text{HI} = \text{NH}_4\text{Cl} + \text{I}_2$), it gives a "free chlorine" reaction equivalent to the original chlorine used in its formation.

The term "available chlorine" was originally used in the evaluation of bleaching powder. The weight of chlorine liberated on the acidification of a given weight of bleaching powder was expressed as a percentage and called "available chlorine." The method of estimation employs an oxidation reaction; either the iodine liberated from potassium iodide is titrated against a standard solution of sodium thiosulphate: (a) $\text{CaOCl}_2 + 2\text{HI} = \text{CaCl}_2 + \text{H}_2\text{O} + \text{I}_2$, (b) $2\text{Na}_2\text{S}_2\text{O}_3 + \text{I}_2 = 2\text{NaI} + \text{Na}_2\text{S}_4\text{O}_6$, or an emulsion of the powder in water is titrated with alkaline sodium arsenite solution: $\text{CaOCl}_2 + \text{Na}_3\text{AsO}_3 = \text{CaCl}_2 + \text{Na}_3\text{AsO}_4$.

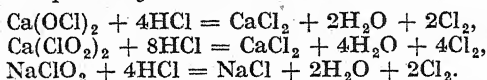
The formula $\text{Ca} \begin{smallmatrix} \text{Cl} \\ \diagup \diagdown \\ \text{OCl} \end{smallmatrix}$ was suggested by Odling for bleaching powder. A pure substance having this formula would contain 55.8 per cent. of "available chlorine." The commercial product contains 30 to 35 per cent. of "available chlorine," *i.e.*, 58 per cent. of this pure substance, the remainder consisting chiefly of hydrated lime. The chlorine estimated corresponds, therefore, with the amount present in the molecule and also with the amount of chlorine used in its manufacture.

The entity which is really assessed in this estimation of "available chlorine" is the oxidation value of the hypochlorite contained in the molecule,

since, referring to the equations above, $\text{ROCl} \equiv \text{O} \equiv \text{I}_2 \equiv \text{Na}_3\text{AsO}_3 \equiv \text{Cl}_2$, where R- can be CaCl_2 , or, Na-. This fact becomes apparent when considering the "available chlorine" figure of other hypochlorite preparations. For example, calcium hypochlorite preparations are now on the American market which have 70 to 74 per cent. "available chlorine." Pure calcium hypochlorite would react according to the equation: $\text{Ca}(\text{OCl})_2 + 4\text{HI} = \text{CaCl}_2 + 2\text{H}_2\text{O} + 2\text{I}_2$. Since $2\text{I}_2 \equiv 2\text{Cl}_2$ the substance contains 99 per cent. "available chlorine."

It is possible that calcium chlorite and sodium chlorite [$\text{Ca}(\text{ClO}_2)_2$ and NaClO_2] may be manufactured on a commercial scale, and these compounds would have 162 per cent. and 157 per cent. of "available chlorine" respectively. To overcome the anomaly Hedgepeth and Buswell (1939) have suggested the following definition for "available chlorine": Available chlorine is the weight of chlorine given by reacting a given weight of sample under ideal conditions with an excess of hydrochloric acid, the result to be expressed as a percentage.

The three compounds just cited react thus:—

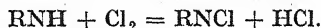


The same anomaly arises when considering the "available chlorine" of chloramines and the organic chloramino compounds, such as monochloramine ($\text{NH}_2\text{Cl} \equiv \text{Cl}_2$), and "Chloramine-T" (sodium *p*-toluenesulphochloramide) ($\text{CH}_3\text{C}_6\text{H}_4\text{SO}_2\text{NCINa}, 3\text{H}_2\text{O} \equiv \text{Cl}_2$).

It is interesting to note that, though the figure for "available chlorine" of hypochlorite or chloramine is twice the chlorine content of the compound, the figure is equivalent to the chlorine used in the formation of the active molecule. For example, one half the chlorine absorbed by cold hydroxide or carbonate goes to form inactive chloride:—



Similarly, one half the chlorine used in the formation of chloramine goes to form inactive chloride:—



Measurements of "free chlorine" are made on the same basis as those for "available chlorine": the ortho-tolidine method of estimation of "free chlorine" measures the oxidation value of the active ingredient (in acid solution) and the result is expressed in terms of chlorine. Thus, as with "available chlorine," a measurement of the chlorine used in forming the active molecule (hypochlorite or chloramine) is made.

Pure chloramines are unstable, oily liquids with an acrid odour and are prepared from chlorine and ammonia or ammonium salts. Nitrogen trichloride or trichloramine ($\text{NH}_3 + 3\text{HOCl} = \text{NCl}_3 + 3\text{H}_2\text{O}$) is of no interest in water chlorination in which ordinary conditions do not permit its formation. It is said to be formed only when the *pH* is below 4.4.

The reactions taking place between chlorine and ammonia in the very dilute solutions which prevail in water chlorination are not fully understood. They probably vary according to the character of the water in respect of *pH*, saline and organic constituents, the ratio of chlorine to ammonia, etc., and are doubtless incomplete. Monochloramine only is said to be formed in water of high *pH* (over 8.5) and a mixture of monochloramine and dichloramine in waters of *pH* 4.4 to 8.5, the proportion of the latter rising as the *pH* falls, so that at *pH* 7.0 there are approximately equal parts of each (Chapin, 1929, 1931). It has been suggested that ammonium hypochlorite (NH_4OCl) is also formed, particularly when water is treated with very small doses of ammonia and chlorine.

Ammoniation of Water. Ammonia (NH_3) is a colourless gas with a characteristic pungent odour. It is very irritating and if inhaled in sufficient quantity may prove fatal. Pressure cylinders of liquid ammonia are used in large waterworks in preference to ammonium sulphate. They must be handled with care to prevent leakage, operated in a dry, reasonably warm place, but must not be kept near any fires, radiators, hot-water pipes, etc.

Ammonia is incombustible and a non-supporter of combustion. It is lighter than air, and very soluble in water, one volume of water dissolving 1,298 volumes of ammonia at 0°C . and 710 volumes at 20°C . Aqueous solutions of ammonia are strongly alkaline and very corrosive to copper and its alloys. Commercial "aqua ammonia" has an ammonia content of 29 per cent. (specific gravity 0.88).

Ammonia gas is readily liquefied by pressure, and, since great cold is produced on release of the pressure and evaporation of the gas, liquid ammonia is used for refrigerating purposes. At waterworks, the gas is released from the cylinders under controlled conditions, the plant being similar to "gas-chlorine" apparatus. An aqueous solution of ammonia can be made in a small flow of water which is then mixed with the main flow of water to be treated, or the gas can be injected directly into the water. Owing to the precipitation of hardness salts by ammonia, blocking of fine tubes and jets occurs with hard waters. This can be avoided by using softened water for the ammonia "feed" or by adding to the feed-water 1 to 1.5 parts per million of sodium hexametaphosphate (Calgon). Alternatively, ammonium sulphate can be used instead of ammonia.

Ammonium sulphate is a by-product of the gas works industry. It is a white crystalline solid, having an ammonia content of approximately 25 per cent. It is very soluble in water and ordinary solution feed apparatus are used in the ammoniation of water supplies. In many cases this method of ammoniation is more convenient than the liquid-ammonia method.

Ammonia Dosage and Contact Time. The dosage of ammonia required is very variable and must be carefully adjusted in each individual case. It depends primarily on the natural ammonia content of the water and the dose of chlorine applied. Theoretically, ratios of chlorine to ammonia of approximately 4 : 1 for monochloramine and 8 : 1 for dichloramine are required, but in practice the ratio is usually between 3 : 1 and 2 : 1 and a certain latitude is generally permissible. The optimum ratio for the prevention of chlor-phenolic or iodoform odour and taste, and to secure an adequate margin of bacterial safety in the available contact period, must be found by trial in every supply. It is seldom advisable or necessary for the ratio to be less than 2 : 1, but some waters, including deep borehole supplies of great organic purity, naturally contain ammonia as high as 1 part per million. Difficulties arise in the chlorination of such waters since a normal chlorine dose would not exceed 0.25 part per million, but this would give an inverse ratio, possibly of 1 : 4, when germicidal activity would be much retarded. The application of 2 to 3 parts per million of chlorine to such waters, in order to obtain a suitable chlorine/ammonia ratio for reasonably rapid sterilisation, is excessive and produces marked odour. Dechlorination is, therefore, necessary.

The contact time required in ammonia-chlorine treatment is considerably longer than in simple chlorination and this fact must be kept in mind when adopting the process and adjusting the ammonia dose. Bacteriological confirmation of the suitability of the chemical doses in

relation to the contact time available must be obtained in every supply. With careful arrangement of dosage, contact periods of one to four hours usually suffice. In a few instances where ammonia has been excessive and pH high, we have found *Bact. coli* to survive eight to twelve hours' exposure in water showing well-marked residual chlorine reactions. In this connection a word of warning is appropriate with reference to the short circuiting of water which takes place in tanks and reservoirs. The nominal retention of water is seldom, if ever, completely obtained in practice even with the most carefully designed baffling systems and it is advisable, therefore, to allow a good margin of safety in designing contact tanks.

The point of application of ammonia differs according to the circumstances of the waterworks, but in most instances it is added before the chlorine. The interval between the two need not be long, but to obtain the best results in the prevention of odour and taste the ammonia should be dispersed throughout the water before the chlorine is introduced. In some cases, however, where odour and taste troubles do not arise, and a quick germicidal action is required, chlorine is admitted first, and, after a short contact time, ammonia is added to stabilise the residual chlorine. Ammonia added before filtration is partially or completely lost, particularly in the summer months. This is doubtless due to biological activities and is observed in both slow sand beds and rapid filters.

"Preformed chloramine" is the term used when both ammonia and chlorine are added to a small portion of the water which is then added to the main bulk of the water to be treated.

Applications of Ammonia-Chlorine Treatment. Ammonia-chlorine treatment is inadvisable when the available contact time is short, particularly if the pH of the water is high. Its use is indicated when it is required to maintain a residual chlorine reaction in a water for a long period of time, such as in reservoirs, or mains of great length. Ammonia is also beneficial in preventing chlor-phenolic odours and tastes which are prone to develop in some waters after chlorination. It also permits a higher residual chlorine reaction to be carried by a water without causing complaints of chlorinous odour. This value varies considerably in different waters, and in those which are of a high standard of organic purity such low chloramine residues as 0.15 part per million may cause complaints of chlorinous odour, particularly at the hot-water taps in bath-rooms, etc.

Ammonia does not remove the earthy, musty, weedy and algal odours commonly found in waters derived from surface sources, but ammonia-chlorine treatment is useful in restraining certain algal growths in raw water reservoirs and open tanks in which chlorine alone would be quickly destroyed and thus rendered ineffective.

Swimming bath waters are often treated by the ammonia-chlorine process, but strict control is necessary owing to the marked increase in the ammonia content of the water which arises from urinous and other contaminations from the bathers. Inefficient germicidal action of

chlorine often occurs in swimming baths owing to the presence of excess of ammoniacal compounds in the water.

Ammonia-chlorine-treated waters can be dechlorinated by the same methods as are used for chlorinated waters.

Control of Chlorination. To obtain the maximum benefit of chlorination, correct application and strict control are essential. Faulty methods and lax supervision bring risks to the consumers and disrepute to the process. Chlorinating apparatus include devices showing visible evidence of operation, the rate at which chlorine is being passed into the water, and also in some cases, automatic recording instruments producing a continuous chart record of the date, time and chlorine dose. None of these is entirely reliable, and, in any case, it is required to know the residual chlorine content of the treated water after the allotted contact time, *i.e.*, the amount available for germicidal action after the chlorine demand of the water has been satisfied. Instruments are available to record the chlorine residuals, but these also are not infallible, and chemical tests for free chlorine should be carried out as part of the daily routine. The ultimate tests for efficiency are bacteriological examinations of the final water.

The chemical tests usually employed to demonstrate the presence of free chlorine and chloramines in water are the "ortho-tolidine" test and the "iodide-starch test." Both take advantage of the oxidising action of chlorine and neither is specific. The iodide-starch test, *without acidification*, is, however, satisfactory in testing water for free chlorine since there is no interference by nitrite, iron and manganese. A third test, sometimes used when comparatively high residual chlorine reactions are expected, is a colorimetric method, using a solution known as "Chlorotex," which appears to be specific.

The Ortho-Tolidine Method. This test consists in adding 0.5 c.c. of a solution of ortho-tolidine hydrochloride (see Appendix) to 50 c.c. of the water, when a yellow colour develops in the presence of residual chlorine or chloramine. Under suitable conditions of test, so small a trace as 0.01 part per million can be detected. With waters of high alkalinity, the amount of acid contained in 0.5 c.c. of the reagent may not suffice to acidify the 50 c.c. of water, when, in the presence of chlorine, a blue-green, instead of a yellow, colour develops. This can be avoided by using double the volume of the ortho-tolidine reagent.

The intensity of the yellow colour produced is approximately proportional to the amount of residual chlorine or chloramine present in the water. If suitable precautions are observed, a reasonably correct estimation of the amount present can, therefore, be made by matching the colour with standard colour solutions. Matching discs or slides of celluloid or glass, tinted to the same depth as the standard colour solutions, are manufactured and are in common use in "comparators" and similar apparatus.

The ortho-tolidine method is interfered with by certain other fairly common constituents of water, the principal of which are nitrites, ferric iron and manganic manganese. These produce similar yellow colour,

and the presence of residual chlorine may be recorded when there is none. The possibility of "false" ortho-tolidine reactions must not, therefore, be overlooked, particularly in the control of chlorination operated to yield only a small residuum, and also when testing ammonia-chlorine-treated drinking waters of inferior organic purity, and swimming bath waters. The development of nitrites in ammonia-chlorine-treated water supplies is often a rather delayed effect observed in samples drawn from the distribution mains. There is usually a fall in the free ammonia figure followed by a decreasing residual chlorine reaction as nitrites develop in the water. Contact of the water with certain metals, such as steel, zinc and lead, accelerates this process. We have observed in laboratory experiments the rapid development of nitrites in water having high residual chloramine and organic matter, when placed in contact with bright lead. Furthermore, lead may be acquired by the water in the process whether the pH and alkalinity are high or low. This action has not, however, proved troublesome in practice. Nitrites and free chlorine are incompatible, but nitrites and chloramines can co-exist in water.

In addition to nitrites, iron and manganese, certain organic compounds may be present in water and give a "false" ortho-tolidine reaction. Also, the ortho-tolidine test is impaired or inapplicable in waters already possessing noticeable yellow and yellow-brown colours, such as many derived from moorland and upland sources. In these cases the starch-iodide test, without acidification, can be applied. The presence of suspended matter also impairs the test and prior centrifugalisation of the water for its removal should, therefore, be carried out.

The permissible limit given in the "Standard Methods for the Examination of Water and Sewage" (published by the American Public Health Association) for interfering substances when using the ortho-tolidine test are 0.3 part per million of iron, 0.01 part per million of manganic manganese and/or 0.3 part per million of nitrite nitrogen. The majority of water supplies, particularly at the usual purification stage of chlorination, do not contain these interfering substances in quantities reaching the above limits. In our experience, nitrite nitrogen can, however, cause significant interference at concentrations of less than 0.3 part per million when ortho-tolidine tests are being made for residual chlorine reactions of the order of 0.1 part per million. There seems to be no strict quantitative relation between nitrite nitrogen and the colour which it produces with ortho-tolidine reagent, but measurable colour may be given with waters containing 0.05 part per million, and occasionally even less, of nitrite nitrogen.

Ortho-tolidine tests should be carried out immediately after collection of the sample, since reduction of free chlorine will take place if there is any material delay, such as by transporting the sample to a distant laboratory.

The test is best carried out in daylight, but reasonably correct results can be obtained at night by the use of "daylight" electric lamps.

The full intensity of the yellow colour is not developed immediately on adding the ortho-tolidine reagent and is delayed by cold. If, there-

fore, the temperature of the water is very low and estimation is required, it is advisable to warm the water to 20° C. The colour reaches its maximum intensity within fifteen minutes, after which it may fade, particularly when exposed to air and sunlight. After addition of the reagent the sample under test should, therefore, be placed in the dark for ten to fifteen minutes and the determination then immediately made.

The "flash-reading" method of ortho-tolidine testing, developed in connection with "break-point" chlorination, consists of the addition of the reagent in the usual manner and comparison with colour standards immediately, after one minute and again after five minutes. If there is little increase in the intensity of the colour after one minute and five minutes, over that produced immediately, the "break-point" has been reached or exceeded. If, on the other hand, there is noticeable increase in colour in that time, the "break-point" has not been reached. Adjustment of the chlorine dosage is, therefore, made accordingly (Laux, 1940).

Measurement of the Residual Reaction. Measurement of the approximate amount of free chlorine present can conveniently be made in a comparator, using tinted glasses or discs for matching the colour, and the result is obtained directly in parts per million. The standard colour glasses must, of course, be accurate and the working instructions issued by the makers of the apparatus closely followed.

Colorimetric estimation can be made in the laboratory by matching with standard colour solutions. In this case, 1 c.c. of the ortho-tolidine reagent is added to 100 c.c. of the water under examination, contained in a special long Nessler tube having the 100 c.c. graduation mark at 300 mm. from the bottom. The same tubes are used for the standard colours, the precautions previously mentioned in respect of temperature, time, etc., being observed.

Two stock standard colour solutions are prepared as follows :—

1. *Copper Sulphate Solution.* Dissolve 1.5 grams of copper sulphate and 1 c.c. of concentrated sulphuric acid in distilled water and make up to 100 c.c.
2. *Potassium Dichromate Solution.* Dissolve 0.025 gram of potassium dichromate and 0.1 c.c. of concentrated sulphuric acid in distilled water and make up to 100 c.c.

Varying amounts of these two solutions are added to the Nessler tubes and diluted to 100 c.c. with distilled water for the preparation of the colour standards according to Table I :—

The result is obtained directly in parts per million of chlorine, and if the water under test contains more than 1 part per million it can be diluted with specially prepared distilled water having no chlorine demand. To obtain reliable results, it is essential to follow the instructions precisely. If tubes, giving 300 mm. depth of water are not available, and others, such as the common shorter Nessler glasses, are used, re-standardisation of the matching colours is necessary.

In the presence of interfering substances the starch-iodide and Chlorotex methods can be used.

Starch Iodide Method. To 50 c.c. of the water add a crystal of potassium iodide and 1 c.c. of starch solution (see Appendix). With

0.05 part per million of chlorine a very faint blue tint develops. Deep blue to black colours appear with larger amounts of chlorine. Quantitative measurement of the chlorine can be made by treating a large volume of the water, *e.g.*, 1 litre, in a similar manner and titrating the liberated iodine with N/800 sodium thiosulphate solution (1 c.c. N/800 thiosulphate solution is equivalent to 0.0443 mg. of chlorine).

Chlorotex Test. The Chlorotex reagent and testing set are manufactured by the British Drug Houses Limited. 50 c.c. of the water under test are rapidly added to 5 c.c. of the reagent, mixed, allowed to stand one minute and the colour produced compared with the tints given on a colour chart supplied with the set. In the presence of 0.1 to 0.2 part per million of chlorine a pink colour develops which changes to red at 0.5 part per million, purple at 0.6 part per million and blue at 1 part per million. Green and brown colours occur when the chlorine content exceeds 1 part per million.

TABLE I

Copper Sulphate Solution.	Potassium Dichromate Solution.	Chlorine.
c.c.	c.c.	Parts per million
0.0	0.8	0.01
0.0	2.1	0.02
0.0	3.2	0.03
0.0	4.3	0.04
0.4	5.5	0.05
0.8	6.6	0.06
1.2	7.5	0.07
1.5	8.2	0.08
1.7	9.0	0.09
1.8	10.0	0.10
1.9	20.0	0.20
1.9	30.0	0.30
2.0	38.0	0.40
2.0	45.0	0.50
2.0	51.0	0.60
2.0	58.0	0.70
2.0	63.0	0.80
2.0	67.0	0.90
2.0	72.0	1.00

(From "Chlorination of Water," by Race, after Ellms and Hauser.)

Effects of Chlorination of Water. The most important effect of chlorination is the destruction of bacteria and this is the commonest purpose of its application to water. In larger doses, it is also used as an oxidising and decolorising agent, and, under certain conditions, deodorisation may be obtained.

Algæ, protozoa and other low forms of life found in surface waters are more resistant than bacteria to chlorine, but algal growths in reservoirs and tanks can be controlled by economical, though comparatively high, doses of chlorine. Slime production, depending on biological growths, in tubes of coolers, etc., can be restrained by

chlorination, and the method is in common use at industrial premises where large volumes of water are recirculated. It can also be usefully employed at waterworks where impure water is conveyed through long lengths of mains to purification works, etc.

Fish. The eggs of fish are said to be very sensitive to chlorine and to be destroyed by 0.1 part per million. The effect on fish varies considerably, some, such as trout, being more susceptible than others such as carp. According to Flin, Weston and Bogert (1927), trout were killed in three hours by water containing 0.17 part per million of chlorine, whereas eels, perch and gold-fish were apparently unaffected by 1.6 parts per million, but were killed by 2.5 parts per million on the second day of exposure.

Corrosion. Although inactive when absolutely dry, chlorine is highly corrosive to metals in the presence of moisture. Its presence in water supplies in minute traces of less than 0.2 part per million does not, as a rule, cause any corrosive troubles in respect of pumps, mains, domestic pipes and fittings, but at higher concentrations corrosion may become noticeable. Manganese-bronze parts of pumps, domestic ball-valves and taps, and calorifiers of hot-water systems may become corroded when the residual chlorine or chloramine is of the order of 0.3 to 0.5 part per million. Such effects have been observed in many instances during emergency periods when water supplies in distribution are carrying abnormally high chlorine residua.

Rusty water troubles, associated with growths of iron bacteria and production of sulphuretted hydrogen, which are particularly prone to arise in long lengths of distribution mains and dead-end mains in rural areas where the draw-off is small, may sometimes be ameliorated by the presence of residual chlorine or chloramine in the water.

New Mains and Reservoirs. New tanks, reservoirs and mains are usually chlorinated as part of the cleansing process prior to being brought into service. This cleansing process should be thoroughly carried out, since considerable contamination often takes place, particularly of mains when being laid in wet trenches. Satisfactory results are usually obtained if, after thorough preliminary flushing with clean water, the structures are allowed to stand for twenty-four hours filled with water containing 1 to 2 parts per million of chlorine and then again flushed with clean water. Tests should be carried out to ensure that residual chlorine remains and if all the chlorine is lost more should be added until an appropriate residuum remains throughout the contact period.

In emergency treatment when mains may become grossly polluted with sewage, more drastic measures are necessary, and chlorination at concentrations of 10 to 50 parts per million, depending on the circumstances, is required. Advantage is gained by removing as much suspended matter as possible by flushing with water prior to chlorination. Bleaching powder and sodium hypochlorite solutions are often more convenient for emergency chlorination of this character, but gas-chlorination by cylinders of liquid chlorine is more efficient, since it

does not increase the pH value of the water nor cause precipitation of calcium carbonate in hard waters. Chlorination is more effective at low pH values, and the settlement of calcium carbonate on the surfaces to be sterilised may protect bacteria from the action of the chlorine. All parts of an affected distributing system including service reservoirs, mains, hydrants, service pipes and domestic systems, should be cleansed, and the presence of residual chlorine throughout the whole established by tests. Confirmation of the efficiency of treatment is obtained by bacteriological examination of samples of water collected at consumers taps. Until such confirmation has been obtained consumers should be advised to boil the water.

Many engineering problems in connection with public water supplies arise in war-time from damage to waterworks and distribution systems, but boiling of water by the consumers, and chlorination by the authorities are the means by which the spread of water-borne disease is avoided. No other process of treatment has the wide application and efficiency of chlorination in emergency practice.

REFERENCES

- CHAPIN. 1929. *Jour. Amer. Chem. Soc.*, 51, p. 2112.
CHAPIN. 1931. *Jour. Amer. Chem. Soc.*, 53, p. 912
HEDGEPETH and BUSWELL. 1939. *Jour. Amer. Wat. Wks. Assoc.*, 31, p. 2135.
HOUSTON. 1929. 24th Annual Report to Met. Water Bd., London.
LAUX. 1940. *Jour. Amer. Wat. Wks. Assoc.*, 32, p. 1027.
RACE. 1918. "Chlorination of Water." John Wiley & Sons, New York.
RIDEAL. 1910. *Jour. Royal San. Inst.*, 31, p. 33.

CHAPTER XLII

THE PURIFICATION OF WATER BY MEANS OF LIME

It was noted by P. Frankland, in 1885, that considerable reduction of bacteria occurred in water as a result of softening by Clark's process. This observation has often been confirmed, and the following figures, taken from our records, provide an example of the bacterial improvement effected by efficient lime softening of a supply obtained from deep wells in the Chalk.

TABLE I

	Hard Water.	Softened Water.
No. of Samples	25	25
Average No. of Bacteria on Agar 1 day, at 37° C., per c.c.	111	11
Average No. of Bacteria on Gelatin 3 days, at 20° C., per c.c.	1,050	290
Percentage of Samples containing Bact. coli in :—100 c.c.	24	12·5
10 c.c.	60	0
1 c.c.	16	0

This result is achieved mostly by mechanical means, the bacteria being removed by sedimentation with the precipitated carbonate.

Frankland (1894) observed in experiments the purifying effect of lime on both well and river water (Thames), and found that the presence of an excess of lime, *i.e.*, an amount in excess of that required to neutralise free carbonic acid and remove temporary hardness, had a direct bactericidal action.

In view of these facts, it is not surprising that lime came into use for purification purposes as well as for softening, and, according to Rideal (1914), the river water supply to Cincinnati, Ohio, was, in 1899, purified by excess lime (3 to 4 grains per gallon excess CaO) with satisfactory results as regards removal of bacteria and organic matter. The water was recarbonated to remove the excess of lime.

The lime process of purification was investigated in this country by Houston (1912) who reported: "I have found that quicklime (about 75 per cent. CaO) added to raw Thames water in the proportion of one part of quicklime to 5,000 parts of water kills *B. coli* in 5–24 hours, under laboratory conditions of experiment."

With this dose an excess of 0.007 per cent. (4.9 grains per gallon) of CaO was left in the water.

Details of Houston's laboratory experiments are contained in his Eighth Research Report to the Metropolitan Water Board (1912). Confirmatory results were obtained in field experiments carried out at the Sunbury works of the Metropolitan Water Board, and are described in Houston's Eleventh Research Report. He also observed that with 24 hours' contact even less than 0.007 per cent. of excess CaO sufficed for bactericidal purposes, and he suggested that the residual alkalinity could be neutralised by the addition of "not less than 25 per cent. of stored water." He also stated: "speaking generally, the bactericidal dose with hard waters would seem to be about 1 to 5,000 and with very soft waters about 1 to 50,000," and "with hard waters it is a case of adding an excess of lime to the major proportion of the total volume, rendering the minor proportion 'safe' by adequate storage, ozonisation, chlorination, or other method, and mixing the two together so as to neutralise the excess of lime and render the whole perfectly innocuous. With soft waters the procedure is to treat the whole bulk of water with an excess of lime and neutralise with carbonic acid, or sulphate of alumina or acid."

The subject was further mentioned in Houston's Ninth, Tenth and Eleventh Research Reports to the Metropolitan Water Board, and in his work, "Rivers as Sources of Water Supply," 1917, he summarises in favour of the excess-lime process of purification in suitable cases.

In 1915, Parliament passed a Bill for the City of Aberdeen approving a scheme of purification consisting of excess-lime treatment, storage for seven days, and filtration at approximately twice the ordinary rate. The water, derived from the River Dee, was very soft and the amount of lime required was therefore small (1 lb. per 10,000 gallons). The results were said to be completely successful (Houston, 1917).

Under the heading "The circumstances under which the excess-lime process appears to be specially attractive," Houston (1914) concludes as follows:—

1. A water bacteriologically impure, which in any event it is proposed to soften.

2. A supply hard as well as impure, situated in a district badly circumstanced as regards alternative supplies.

3. A river water contaminated (or liable to be contaminated), having scarcely any available storage accommodation, and necessitating for waterworks purposes the occasional use of flood water, with mere sand filtration as a safeguard.

4. Wells not sufficiently pure to be used without some form of treatment.

5. Surface waters unduly "soft," and not free from risk of pollution.

6. Mixed supplies, part being impure bacteriologically and the rest above suspicion; the former to be lime-treated and the latter used for neutralisation purposes.

In view of the rapid growth of population in certain parts of Essex,

and the progressive decrease in yield of the deep wells sunk through the London Clay to the Sands and Chalk beneath, it became apparent some years ago that in this county the necessary additional supplies could only be obtained from rivers.

The County Borough of Southend and the Borough of Chelmsford were in urgent need of more water, and attention therefore was given to the River Chelmer, its tributary the Ter, and the River Blackwater, as possible sources to augment the existing wells. These are comparatively small and sluggish rivers rising in and flowing through agricultural areas, the average daily flow being about 12 million gallons in each case. The water is impure and also hard in character (20° to 26.5° , Clark, *i.e.*, grains per gallon). Since a softer water was desired, the use of these river waters necessitated both purification and softening, and the excess-lime process, therefore, came under review. Owing, however, to the absence in this country of any large-scale experience of this process when applied to hard, impure, river waters (the Aberdeen experience was with a very soft water), it was considered essential to prove its efficiency with such waters.

Preliminary laboratory experiments which we had carried out with River Chelmer water gave favourable results, and accordingly we advised that the process was capable of successful practical application.

Examples of the results obtained in these experiments are shown below :—

TABLE II

EXCESS LIME EXPERIMENTS WITH RIVER CHELMER WATER

*Series 1. Showing Effect of Lime**(a) Excess Lime (CaO), 2 grains per gallon. Effect of Contact Time*

	Untreated River Water.	Treated Water after		
		12 hrs.	24 hrs.	72 hrs.
Bacteria per c.c.	12,600	3,400	7	0
Bact. coli in	Present	Absent	Absent	Absent
	1 c.c.	100 c.c.	100 c.c.	100 c.c.

(b) Contact Time, 24 Hours. Excess Lime Varied

	Untreated Water.	Treated Water.	
		No Excess.	1½ Grains Excess.
Bacteria per c.c.	29,850	108	21
Bact. coli	Present	Present	Absent
	0.001 c.c.	1 c.c.	100 c.c.

TABLE II—*continued*

	Untreated Water.	Treated Water.		
		$\frac{1}{2}$ Grain Excess.	$1\frac{1}{2}$ Grains Excess.	2 Grains Excess.
Bacteria per c.c.	43,260	670	540	7
Bact. coli	Present	Absent	Absent	Absent
	1 c.c.	100 c.c.	100 c.c.	100 c.c.

(c) *Contact Time, 24 Hours. Excess Lime, 2 grains per gallon
Various Samples of Water*

	Untreated Water.	Treated Water.
1. Bacteria per c.c.	15,000	2
Bact. coli.	+ 0.1 c.c.	Absent 100 c.c.
2. Bacteria per c.c.	10,000	110
Bact. coli.	+ 0.1 c.c.	Absent 100 c.c.
3. Bacteria per c.c.	14,000	48
Bact. coli.	+ 0.01 c.c.	Absent 100 c.c.
4. Bacteria per c.c.	29,850	21
Bact. coli.	+ 0.001 c.c.	Absent 100 c.c.

*Series 2. Reduction of Hardness, grains per gallon
Average of 100 Experiments*

	Maximum.	Minimum.	Average.
River water	26.5	20.0	23.5
Treated water	16.0	8.5	11.0

The average reduction of organic matter in the treated waters, as indicated by the albuminoid ammonia and oxygen absorbed determinations, was 50 per cent.

In order to confirm these results, the Southend Waterworks Company operated, under our supervision, an experimental station, erected at the junction of the Rivers Chelmer and Blackwater. Twenty-five thousand gallons of water could be abstracted daily for treatment from either river, and experiments were conducted continuously for a period of nine months, with regular chemical and bacteriological control.

In the course of this work, many difficulties in the practical application of the process were encountered and remedies devised.

The following conclusions were recorded in a final summary of the results obtained at this experimental station :—

1. The river waters varied considerably in character, much more than is the case with larger rivers. Often, the change in an hour would be so marked as to necessitate readjustment of the flow of lime-water.

2. There were periods (rarely exceeding four days) following very

heavy rainfall when the river waters became so disturbed that it was inadvisable to abstract them for treatment, and the desirability of making provision for 5 to 7 days' storage of raw water was, therefore, indicated. The quality of the river water, and its suitability for treatment, could be promptly ascertained by determining colour and turbidity, thus permitting early decisions as to closure of the intakes.

3. The important factors in purification by excess lime are the amount of the excess and the contact time. The best results were obtained with 1.0 to 1.5 parts per 100,000 of excess lime and a contact time of 24 hours. Under these conditions it was found that :—

- (a) The bacteria were reduced from thousands to units.
- (b) *Bact. coli* was invariably not found in 100 c.c.
- (c) The organic matter was reduced by 50 per cent.
- (d) The colour was reduced to less than 10 (Hazen Scale).

4. To obtain rapid precipitation, it was necessary to add to the river waters aluminium sulphate in a dose of approximately 1.5 parts per 100,000 before the addition of lime.

5. It was more economical to add the lime in the form of lime-water than as milk of lime.

6. Provided the chemicals were properly mixed in the water, the main bulk of the precipitation and deposition took place in the primary tank of the experimental plant.

7. In order to ensure that at least 1 part per 100,000 of excess lime was uniformly present, careful adjustment of the lime dosage was necessary.

8. A simple colorimetric method using brilliant cresyl blue was devised which enabled the operator to ascertain immediately whether the lime dosage was correct. This indicator has a colour change of blue-green-brown in the pH range of 10.5 to 12.5. When no excess of lime is present and the pH of the water is less than 10.5, it gives a clear, deep blue colour. At pH 11.0 to 11.5 and excess lime of 1.0 to 1.5 parts per 100,000, a pale greenish-blue colour is produced. At pH 11.5 to 12.0 and excess lime of 2.0 to 2.5 parts per 100,000, the colour is a clear green without bluish tinge, but a definite brownish-green or brown colour is not obtained until the pH is over 12.0 and the excess lime exceeds 2.5 parts per 100,000. Experience is necessary in the application of this test and different batches of the indicator do not always give quite the same colour changes. It is advisable, therefore, to install automatic pH recorders which provide a regular, permanent and more reliable record of the pH of the treated water.

9. After twenty-four hours' sedimentation in open tanks, the water was alkaline in reaction, and, when mixed with the well waters, a slight precipitate slowly formed. Neutralisation of the alkalinity was, therefore, necessary, and recarbonation was found to be efficient for this purpose.

10. Rapid sand filtration sufficed to complete the treatment.

This experimental station proved of great value, and the success achieved played a material part in overcoming the opposition to the

proposed abstraction of water from these rivers for public supply purposes.

Subsequently, Parliament passed two Acts authorising the Chelmsford Corporation (1922) to abstract water from the River Chelmer, and the Southend Waterworks Company (1924) to abstract water from the Rivers Chelmer, Ter and Blackwater, and, after purification by excess lime, to use the waters for public supply purposes.

The outfalls of sewage effluents from the towns of Chelmsford and Witham were diverted to points below the waterworks intakes.

The waterworks were duly constructed and have been in successful operation since 1928. They are the only instances in this country where hard, impure, river waters are simultaneously purified and softened by the excess-lime process, and used for public supply purposes.

The waters, both raw and treated, are kept under strict analytical observation by resident chemists, and the final waters have been consistently of the highest standard of purity. A summary of the results obtained will be given later. The works have aroused great interest and have been visited by eminent waterworks engineers from many parts of the world.

The Southend Waterworks are situated at Langford, near the junction of the Rivers Chelmer and Blackwater, and are about twenty miles distant from Southend. The population of the Water Company's area is approximately 200,000, and the average daily quantity of water supplied from the river works is nearly five million gallons.

The river works, which are designed to deal with seven million gallons a day, consist of intakes, raw water storage reservoirs, pumping station and electricity generating station, purification plant, and lime-recovery plant. There are also offices, laboratory, store-rooms and employees' houses.

The river water gravitates from three separate intakes to two open raw water storage reservoirs, each of 30 million gallons' capacity and covering an area of about 5 acres. The water is then pumped to the adjacent purification works. These works include dosing and mixing plant for aluminium sulphate and lime, sedimentation and contact tanks, recarbonation plant, rapid gravity sand filters and a final water reservoir. As a precautionary measure, chlorinating plant is installed for the treatment of the filtered water should an emergency arise. Measuring and recording apparatus are also installed, and means are provided for treatment of the purified unfiltered water with powdered activated carbon to remove odour and taste when necessary.

The river water intakes are occasionally closed for short periods in times of heavy rainfall.

At the purification works, the raw water is measured and divided into two fractions, one of which is about four times the volume of the other. Aluminium sulphate is added to the larger portion in such amount as to provide approximately 1 part per 100,000 to the whole. The smaller portion receives lime in such amount that the whole has an

excess-lime dose of about 1.5 parts per 100,000. Constant control of the chemical doses is maintained and a testing bench is conveniently arranged, with taps drawing water from the various mixing, sedimentation and contact tanks so that the attendants can readily ascertain the degree of alkalinity at all stages of purification. Automatic pH recorders are also installed.

The addition of the chemicals is accompanied by agitation, which is maintained, by mechanically-driven paddles, for about thirty minutes as the water passes through the mixing tanks. The water then flows into the primary settling tanks, where the bulk of the precipitate is deposited. From these tanks the supernatant water flows to the secondary or contact tanks, where further slight deposition takes place. The primary settling tanks are conical in shape and have wash-outs at the bottom for the periodical removal of the sludge. The latter is partially dried in lagoons and then transferred to the lime-recovery plant. There it is burnt in an oil-fired rotary kiln, the resulting lime being re-used for the water purification process.

The deposit formed in the settling tanks includes the hardness salts, the suspended solids, organic matter, low forms of life and bacteria. It is therefore an impure sludge from which lime of the highest CaO content cannot be recovered.

The total capacity of the tanks is such that if the maximum amount of water of seven million gallons a day flowed through, a contact time of 24 hours would be obtained before removal of the excess lime by recarbonation. Hence there is ample time for sterilisation of the water, and experience has proved that a much shorter period, even of 12 hours, would suffice.

Removal of bacteria by alumina treatment and lime softening is largely mechanical, being effected by entanglement and deposition in the precipitate. The bacteria are not destroyed and can be redistributed in the water. Free or excess lime is, however, germicidal and the time required to sterilise water is roughly proportional to the amount of the excess.

The water, as it leaves the last of the contact tanks, has been clarified, purified and softened, but it retains about 1 part per 100,000 of free lime. This is undesirable and has the disadvantages that it slowly gives rise to slight turbidity and deposit, and imparts a faint metallic or astringent taste to the water. Removal of the excess alkalinity is, therefore, necessary, and is effected by adding carbon dioxide to the water. This CO_2 is produced by the combustion of metallurgical coke and is purified before injection into the water. The carbonated water is retained in a reaction tank for two to three hours before filtration, and the free lime is thus converted to calcium bicarbonate which imparts a trace of temporary hardness to the water.

Carbonation is controlled by automatic pH recorders and indicator solution tests, the final reaction of the water being adjusted to 8.0-8.5. Treatment is completed by rapid sand filters, the installation comprising 14 units, permitting an average filtration rate of approximately

60 gallons per square foot per hour. All that is required of the filters is the removal of a few particles of chalk and activated carbon.

The water then gravitates to a covered balancing reservoir of 500,000 gallons' capacity, from whence it is pumped to a covered service reservoir before distribution to the district.

Treatment by activated carbon has been found desirable for the removal of faint earthy or musty odours which occasionally persist in the final waters. These odours are associated with biological growths in the rivers and raw water reservoirs, and "turn-over" in the reservoirs. The normal processes of purification reduce, but do not entirely remove, these odours, and many of the available methods of deodorisation were tried, but without complete success. Finally it was found that activated carbon was the most efficacious, and the addition of a small dose of the powdered carbon (2 to 10 parts per million) to the water prior to rapid sand filtration proved the most satisfactory method in this instance. It is necessary to apply this treatment only at certain times of the year, but it has been found that a small dose of activated carbon improves the palatability of the water at all times. This treatment which started in 1980 as an intermittent measure has, therefore, become continuous. In view of the fact that it is added to the purified water, the carbon is sterilised by heat as a precautionary measure before use. The results of activated carbon treatment have been most successful, and, since its adoption, no complaints of odour and taste in the water have been received.

The favourable results obtained in the preliminary laboratory experiments and at the Langford experimental station have been fully confirmed in the large-scale application of the excess-lime process at the Southend Waterworks.

Daily tests and analyses are made in the works laboratory, and we also carry out regular independent examinations of samples collected at the waterworks and in various parts of the area of supply.

A summary of our results, obtained on a consecutive series of samples is shown in Table III.

The following points are worthy of note :—

1. Colour and suspended matter are consistently removed, as are also odours and tastes.
2. The organic matter, as estimated by albuminoid ammonia and oxygen absorbed determinations, is reduced by 50 per cent.
3. The hardness is uniformly reduced below the statutory limit, imposed in this instance, of 15 parts per 100,000.
4. Bacteria are almost entirely removed.

The results show 100 per cent. first-class samples as regards coliform bacteria (absent from 100 c.c.), and the reduction in sporing anaerobes (*Cl. welchii*) effected by this process is greater than that obtained by other methods of purification, such as filtration and chlorination.

5. The final water is non-corrosive, and samples collected from the service mains are of the same high standard of purity as those collected at the waterworks.

The process has, therefore, proved practicable and efficient, and it is worthy of consideration whenever the treatment of hard, impure water (the hardness being mostly "temporary") is under investigation. The distribution of hard water is not in the public or national interest, and softening of public water supplies should receive more attention in the future than it has had in the past.

The use of lime for the softening of water, or the removal of acidity, iron and manganese, is described in later chapters of this volume.

TABLE III
COMPARATIVE ANALYSES OF RAW AND TREATED WATERS
(Averages)

Chemical Results in Parts per 100,000.	Raw River Water (before Storage).	Final Purified Water.	
		Samples collected at Waterworks.	Samples collected from taps on Distribution Mains.*
Turbidity	Traces of suspended matter	Clear and bright	Clear and bright
Colour—Hazen Scale	30	Less than 10	Less than 10
Reaction pH	8.1	7.3	7.6
Total Solids	45.0	29.8	31.7
Chlorine in Chlorides	3.5	3.7	3.6
Hardness : Permanent	8.0	7.6	7.5
Temporary	23.0	4.7	4.7
Total	31.0	12.3	12.2
Nitrogen in Nitrates	0.38	0.29	0.29
Metals, Iron	0.04	0.00	0.00
Free Ammonia	0.043	0.0078	0.0024
Albuminoid Ammonia	0.034	0.0065	0.0060
Oxygen absorbed from Perma- nganate 3 hours at 37° C.	0.325	0.065	0.058
Bacteria on Agar 1 day at 37° C. per 1 c.c.	520	1.5	1.2
Percentage of Samples contain- ing :—			
1. <i>Bact. coli</i> in :			
100 c.c. or less	100	0	0
10 c.c. or less	100	—	—
1 c.c. or less	83	—	—
0.1 c.c. or less	58	—	—
2. <i>Cl. welchii</i> reaction in :			
100 c.c. or less	100	0	0
10 c.c. or less	62	—	—
No. of Samples	100	100	25

* Small admixture with well-water in some samples.

References

- FRANKLAND. 1894. "Micro-organisms in Water."
RIDEAL. 1914. "Water Supplies."
HOUSTON. 1912. 8th Research Report to the Metropolitan Water Board, London ; see also 9th, 10th and 11th Research Reports.
HOUSTON. 1914. "Studies in Water Supply."
HOUSTON. 1917. "Rivers as Sources of Water Supply."
HOUSTON. 1925. 19th Annual Report to the Metropolitan Water Board, London.

DIAGRAMMATIC SKETCH OF TREATMENT PLANT

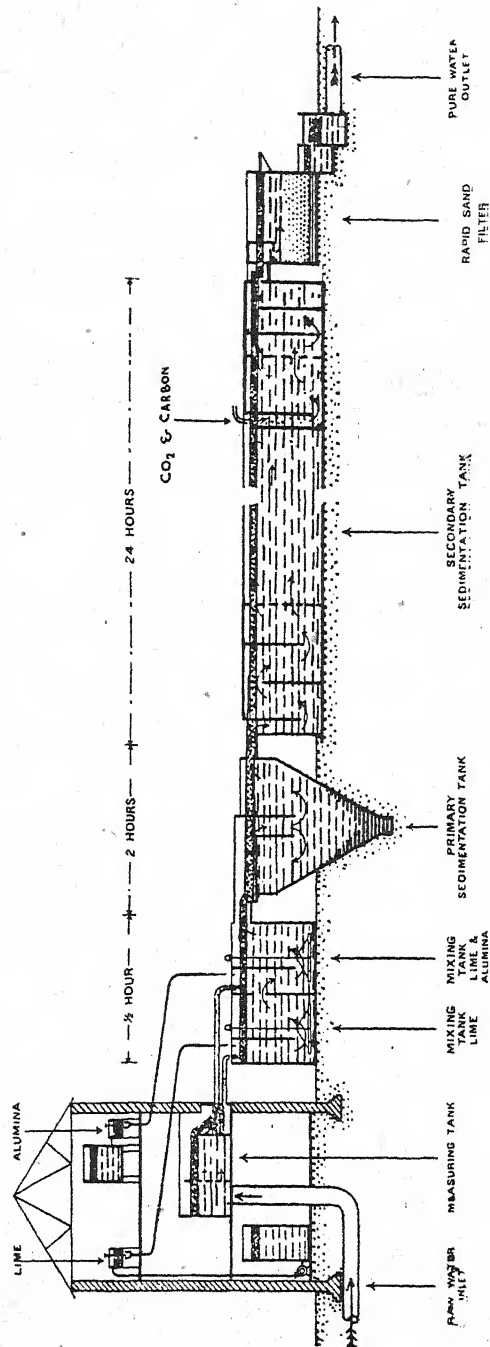


FIG. 27.

CHAPTER XLIII

SOFTENING OF WATER

Disadvantages of Hardness in Water. Undue hardness of water supplies is made apparent to the consumers in several ways, the principal of which are :—soap wastage, or the inability to produce a lather with soap in washing ; the production of adherent slime or curd in wash-basins, baths, and on textiles being laundered ; and the formation of scale or fur in boilers, hot-water pipes, kettles, and other kitchen utensils.

The hardness of public water supplies in this country varies greatly and may be as low as 1 part per 100,000 or, in a few instances, in excess of 50 parts per 100,000. The very soft waters are mainly confined to upland and moorland areas which are mostly found in Scotland, the North of England, and Wales, whilst in the Midlands and the South of England, the majority of supplies have hardness of 20–30 parts per 100,000. Softening is employed only in the minority of the latter, and the hardness is then usually reduced to 10–14 parts per 100,000, which is generally considered suitable. There is no question of doubt that the majority of consumers, both domestic and industrial, prefer soft water, and there are good grounds for this preference.

The advantages of a soft water are briefly as follows :—

1. Saving of labour, soap, and other detergents, in washing and cleaning.
2. Increase in the life of textiles which are frequently laundered, and saving, therefore, in expenditure on wearing apparel, household linen, etc.
3. Restriction of scale formation and subsequent loss of heat in boilers, hot-water pipes, etc., thus effecting economy in fuel consumption and preventing wastage of labour in descaling.
4. Improvement in condition of foods when cooked in soft water, and economy in tea in preparing infusions.

Personal washing and domestic cleansing are much more efficient and less laborious with soft water than with hard, and, hence, soft water conduces to cleanliness which has significant value to the Public Health. Individuals who are subject to chapping and cracking of the skin suffer less with soft water than with hard, but, from the point of view of drinking, no objection arises from hardness within reasonable limits. We are, in fact, aware of private well supplies having hardness of the order of 100 parts per 100,000 which have been habitually in use for many years without apparent ill-effect.

For steam raising in boilers and locomotives, and in laundries and

other industries, soft water is essential and there are only few instances, such as in some breweries, in which hard water is preferred.

It is difficult to assess the comparative advantages of soft water in terms of money, but the claim made that the saving in soap alone, at least balances the cost of municipal softening appears to be well founded. For example, water having hardness of 10 grains per gallon will destroy 17.5 ounces of soap per 100 gallons, and water having hardness of 15 grains per gallon will destroy 26 ounces of soap per 100 gallons (Harwood, 1941).

Assuming a public water supply having hardness of 20 grains per gallon is softened to 10 grains per gallon, such as is usual in municipal softening plants, the saving in soap on the above basis will then be approximately 17 ounces per 100 gallons of water. If the supply is one of 1 million gallons per day and the consumers in various washing uses soften completely by soap only 4 per cent. of the supply * (40,000 gallons), the saving in soap is approximately 425 lbs., which at 6d. per lb. represents £10 12s. 6d. The cost of softening at the waterworks should not exceed 2d. per 1,000 gallons, or £8 6s. 8d. per million gallons, and might well be appreciably less.

Bearing in mind the other advantages mentioned above, it is undoubtedly economically sound, and in the national interest, to soften centrally public water supplies which are hard in character. This would avoid the present great wastage of materials and labour and also the uneconomical private installation of multiple domestic softening plants.

Central softening of municipal supplies can usually be carried out at a cost of between 1d. and 2d. per thousand gallons of water, and such an addition to the consumers' charges is more than balanced by the advantages received. When this fact becomes more widely appreciated, the opposition, often raised by consumers to an increase in water charges to meet the costs of central softening, will doubtless disappear.

The disadvantages of soft waters result from their possible plumbosolvency and corrosive action on metals, for which precautionary measures are often necessary.

Water authorities can justifiably give consideration to softening when the total hardness of the supplies approaches or exceeds 20 parts per 100,000.

Hardness is due to the presence in water of bicarbonates, sulphates, chlorides and nitrates of calcium and magnesium, of which the bicarbonates and sulphates are the most important. Since the bicarbonates are decomposed by heat, carbon dioxide being evolved and insoluble calcium carbonate precipitated, hardness of this character is called "carbonate" or "temporary" hardness, and is responsible for the scale which forms in boilers, hot-water pipes, kitchen utensils, etc. The hardness remaining after boiling is termed "non-carbonate" or "permanent" hardness and is chiefly due to the presence of sulphates of calcium and magnesium.

* Investigations in the U.S.A. have indicated that the average quantity of water actually completely softened is 1 gallon per person per day.

Softening Methods. Water can be softened either by the removal of calcium and magnesium salts or by their conversion into the corresponding salts of sodium. Since the latter do not destroy soap, and are not precipitated by heat to produce scale, they are termed "non-hardness-producing salts." Two distinct softening processes are, therefore, available, in one of which calcium and magnesium salts are precipitated from the water by chemical reagents, and in the other, calcium and magnesium are substituted by sodium by passing the water through a bed of material, known as "zeolite," which possesses base-exchange properties. Each of these processes has advantages and disadvantages, neither is applicable to all water supplies, and careful consideration is necessary in each individual case to decide which of the two best suits the particular circumstances.

Chemicals Employed. The chemicals generally employed in the precipitation process of softening are lime and soda-ash (sodium carbonate), the former being required for the precipitation of carbonate or temporary hardness, and the latter for the precipitation of non-carbonate or permanent hardness.

Lime is available either as quicklime or hydrated lime. In commercial products, the former usually contains approximately 90 per cent. of calcium oxide, CaO , and the latter 95 per cent. of calcium hydroxide, $\text{Ca}(\text{OH})_2$. On this basis, the softening capacity of quicklime is 1.4 times that of hydrated lime, and also, the cost per ton is less. The use of hydrated lime eliminates, however, the troublesome process of slaking, it is easier to store than quicklime, and can be added to water by dry-feed plant.

Soda ash is commercial sodium carbonate and usually contains 95 per cent. to 98 per cent. of Na_2CO_3 . It can be added to water either by solution-feed or dry-feed plant.

Caustic soda, NaOH , could sometimes be used in place of lime and soda ash, but it is less economical, and the final water has higher total solids and sodium carbonate alkalinity, which are undesirable, particularly in boiler feed waters. The process is not used in municipal softening plants.

In the majority of municipal softening plants, lime only is used, since the non-carbonate hardness of the waters is usually the smaller fraction of the total hardness, and the lime-soda process involves considerable additional difficulties and costs. In railway and industrial softening plants both lime and soda are usually employed, since water of minimal hardness is required. The terms "lime softening" and "lime-soda softening" have thus come into use, and, since the chemical reactions are accelerated by heat, the "hot lime-soda" process is sometimes employed in industrial softening installations.

The chemical reactions involved in these processes, and the methods by which the required amounts of the chemicals are ascertained and controlled, have been described in Chapter XX.

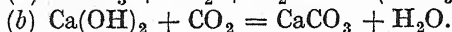
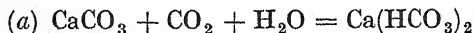
Lime Softening. This process, developed by Dr. Clark of Edinburgh, in 1841, is often referred to as Clark's process. It consists of the addition

to the water of a sufficient quantity of lime to react with both the free carbonic acid and the carbonic acid combined in the bicarbonates of calcium and magnesium, which are then precipitated as the carbonate and hydroxide respectively. If, as is sometimes the case, sodium bicarbonate is also present in the water, an adjustment of the lime dose will be required, since, although it does not cause hardness, sodium bicarbonate reacts with lime according to the equation: $2\text{NaHCO}_3 + \text{Ca(OH)}_2 = \text{CaCO}_3 + \text{Na}_2\text{CO}_3 + 2\text{H}_2\text{O}$. In large installations, quick-lime, being more economical, is used in preference to hydrated lime and is slaked on the site. Hydrated lime is, however, much less troublesome, for slaking requires careful attention. The lime is then converted, in mechanically operated mixing tanks, into cream of lime in some installations, or saturated lime-water in others, by the addition of water which preferably should be soft water. Cream of lime is a suspension of hydrated lime in saturated lime-water, and saturated lime-water contains approximately 100 parts per 100,000 of lime (CaO). The former, being the more economical, is usually employed in large-scale plants. The lime-water or cream is mixed as intimately as possible with the water, which is then retained in tanks for a sufficient time to permit settlement of the precipitate. Aluminium sulphate, sodium aluminate, or both, are sometimes added to the water to facilitate precipitation and deposition, particularly when the magnesium content of the water is relatively high. In older installations, tanks of sufficient capacity to allow 8, 10, or even 15 hours' sedimentation were provided, and in view of their large size these tanks were usually uncovered. Whenever possible, covering is advisable in order to avoid the disadvantages of exposing water to light and to atmospheric contaminations. Also, precipitation and settlement are much delayed by the low temperatures of the winter months. In some cases, tanks are operated in series, the precipitate being removed by continuous flow sedimentation, but in others the "fill and empty" system with quiescent settlement is employed.

In order to avoid the costs involved in the construction of large, covered, sedimentation tanks, removal of the suspension by passing the lime-treated water through a series of canvas sheets or cloths (Haines process) is sometimes employed. In industrial and small private softening plants, strainers composed of wood-wool are used for a similar purpose.

After settlement in tanks, the supernatant water is drawn off, and, in some cases, is distributed without further treatment, whilst in others, it is filtered by rapid sand filters. Lime softening of municipal supplies has the disadvantages that, even with long sedimentation, the softened water retains a trace of chalk in suspension unless subsequently efficiently filtered, and also gives rise to slow precipitation of calcium carbonate. The former causes a loose deposit in mains, pipes, etc., but the latter, which consists of crystalline calcium carbonate, produces a hard, adherent incrustation on the sand grains of filters and in meters, mains, pipes, etc.

Recarbonation. Lime softened water is a supersaturated solution of calcium carbonate and, hence, is unstable. In the absence of carbon dioxide, crystallisation of calcium carbonate gradually takes place, but, if carbon dioxide is supplied, calcium bicarbonate, which is soluble, is formed. Also, a slight excess of lime over the theoretical requirement is often necessary in water softening, particularly when appreciable magnesium hardness is present, and free lime (caustic alkalinity) may then be present in the softened water. The addition to the water of carbon dioxide, *i.e.*, recarbonation, is applied for the correction of both of these conditions, the reaction taking place being represented by the formulæ :—



In order to overcome “after-deposition” and caustic alkalinity, recarbonation of the softened water (see Chapter XLII) is sometimes employed in municipal plants. Carbon dioxide, produced in coke furnaces, is purified and injected into the water, when the reverse process of softening takes place, *i.e.*, calcium carbonate is converted into soluble bicarbonate. By this process the pH value of the water is reduced, the hardness slightly increased, and the calcium carbonate incrustation of sand filters, mains, pumps, etc. is restrained. The process of recarbonation is, however, complicated and attended by various operational difficulties. Carbon dioxide is corrosive, the required dose in any particular case is variable, its diffusion throughout the water requires special methods, and the control is difficult. Recarbonation has, therefore, not proved an unqualified success, and, as an alternative process for the prevention of carbonate incrustation by lime-softened water, the addition of sodium hexametaphosphate [$\text{Na}_2(\text{Na}_4\text{P}_6\text{O}_{18})$], known as “Calgon,” has recently been introduced. The addition to the softened water of so small a dose of hexametaphosphate as 0.25–0.5 part per million prevents or delays the after-deposition of calcium carbonate and provides a simple, economical alternative to the complex and troublesome process of recarbonation. It is added as a solution (usually about 5 per cent.) by ordinary solution-feed apparatus. Care must be exercised to avoid overdosing, otherwise pre-existing deposit in mains may be detached in masses sufficient to cause blocking of meters and service pipes.

Sludge Disposal. The disposal of the sludge from lime softening plants has also proved a hindrance to the process. This sludge is very voluminous, since it contains much water when drawn off from the tanks, and its dry weight is approximately three-and-a-half times that of the lime which has been added to soften the water. The sludge is tanked or lagooned and as much as possible of the water run off, but after air drying, 30–40 per cent. of water usually remains. The deposit may then be dug out and disposed of on the land as a fertiliser in agricultural areas. In suitable instances, in which a clean calcium carbonate sludge is produced, it is an economic proposition to dry it

completely, sieve, and market the powdered chalk obtained, for industrial purposes. Alternatively, the sludge can be dried, recalcined, and the lime thus produced reused for softening, but this has not proved an attractive procedure at waterworks. These available means of disposal have not so far sufficed, and the accumulation of large unsightly mounds of chalk deposit in the vicinity of lime softening plants is often to be found.

Improved Methods of Lime Softening. The extension of lime softening has been restricted owing to the difficulties of the process, but these difficulties are gradually being overcome. The recent introduction of improved designs of tanks, in which pre-formed sludge, known as a "sludge blanket," is retained, has led to notable improvement. The "Accelerator" and the "Precipitator," both of which were developed in America, are examples of such tanks, and are now in use in this country. By their use, the chemical reactions are more quickly completed and the removal of the suspension accelerated and improved. It is claimed that the softening process can be completed and the water clarified in a period of less than three hours, and, since they are not unduly spacious, the tanks can be properly housed. The lime-dosed water enters these tanks at the bottom, where it comes in contact with the sludge blanket, and, after mixing by mechanically-driven paddles, it flows upwards through the sludge blanket, and clear, softened water passes into collecting channels at the top. This water need not be filtered in industrial installations, but rapid sand filtration is advisable in municipal supplies. The water is said to be stabilised and not subject to after-deposition of calcium carbonate, but this has not yet been proved by long experience, and the addition of hexametaphosphate is advisable as a precautionary measure. Sludge is continuously bled off from the tanks, and, after concentration, is dried and disposed of in the usual manner.

Another recent introduction of great interest and possibilities is the Permutit "Spiractor" system of lime or lime-soda softening in which it is claimed that by "catalytic precipitation" the chemical reactions are completed in less than five minutes. The plant consists of a conical steel tank, containing a granular sand-like material, *i.e.*, the catalyst, which can be likened in some respects to the sludge blanket of the tanks previously mentioned.

The raw water, to which the lime has been added, enters tangentially at the lower extremity of the cone and flows upwards with a turbulent spiral motion in which intimate mixing of the water, chemicals and "catalyst" takes place. As the water rises in the cone, its turbulence and velocity of flow gradually reduce, and the calcium and magnesium compounds precipitated by the chemicals adhere to the grains of the catalyst as a hard incrustation. The grains thus enlarge, the heaviest fall to the bottom of the cone, and are periodically drawn off. They can be collected in a tray, when the water runs off, leaving a comparatively dry, sand-like material which can readily be handled. The "catalyst" is replenished as required by adding a new charge into the top of the tank. Softened, and practically clear water flows off from

the top of the tank, and, when absolutely clear and bright water is required, such as in municipal supplies, it can then be passed through a rapid sand filter. When completely soft water is required, such as for boiler and other industrial uses, the lime-softened water passing from the "Spiractor" can, after filtration, be passed through a base-exchange softener for the removal of the non-carbonate or permanent hardness. By such a combination of processes a very suitable water is obtained in which the total solids have been reduced and free carbonic acid and hardness removed.

The claims made for this system are that, in view of the rapid completion of the softening reaction, the plant is small, occupies little space, and can be incorporated in a pressure system, thus avoiding the complication and costs of repumping. It is a comparatively simple plant, has no moving mixing mechanism, and the sludge disposal difficulties of ordinary lime softening plant are greatly reduced, since the waste can be reused and the excess disposed of easily. Should these advantages be realised in large-scale practice, a very notable advance in water softening will have been made and many of the objections and difficulties of lime softening overcome.

The successful practical application of these modern tanks, together with the use of the "sludge blanket," and of hexametaphosphate, promise to reduce considerably the difficulties and costs of lime softening, and should lead to extension of softening in many municipal supplies in which it is required.

Results of Lime Softening. Lime softening should produce a clear and bright water, neutral to faintly alkaline in reaction, giving rise to no deposit on standing, and having no solvent or corrosive action on metals. The total solids and the hardness are reduced, the latter by an amount approximately 2 parts per 100,000 less than the original temporary or carbonate hardness of the water. This is due to the fact that calcium carbonate and magnesium carbonate and hydroxide are very slightly soluble in water, and, hence, the carbonate hardness is not entirely removed. The non-carbonate or permanent hardness is, of course, unaffected, and, when it is required to remove this, soda ash must be used in addition to lime. In the lime-soda process, the same plant is used as in lime softening, and after-deposition in the softened water is particularly likely to take place unless very careful control of chemical doses and other precautions are observed. In these processes of softening, suspended matter, iron and manganese are removed and the water is improved in respect of its organic and bacterial purity. When desired, chlorination can readily be associated with the process, the chlorine being added to the water prior to the addition of lime, and, in view of the long contact obtained in the sedimentation tanks, efficient sterilisation can be assured. With uncovered sedimentation tanks it is preferable, however, to chlorinate the softened water as a separate process, using a covered tank for contact purposes.

Analyses illustrating the results obtained in the softening of a fairly typical, hard, chalk water are given in Table I.

TABLE I
SHOWING ANALYSES OF HARD AND SOFTENED WATERS
Lime-Softening Plant

Parts per 100,000.	Hard Water.	Softened Water.
Turbidity	Clear and bright	Clear and bright
Reaction, pH	7.2	8.1
Free CO ₂	2.0	0.0
Metals—Iron, etc.	Nil	Nil
Nitrogen in Nitrites	Nil	Nil
Nitrogen in Nitrates	0.40	0.40
Free Ammonia	0.0008	0.0008
Albuminoid Ammonia	0.0000	0.0000
Oxygen Absorbed from Permanganate, four hours at 27° C.	0.005	0.005
Temporary Hardness	20.5	2.5
Permanent Hardness	4.0	4.5
Total Hardness	24.5	7.0
Total Solids	31.0	13.0
Calcium, as Ca	9.5	2.5
Magnesium, as Mg.	0.20	0.15
Carbonates, as CO ₃	13.5	2.7
Sulphates, as SO ₄	1.5	1.5
Chlorides, as Cl	1.5	1.5
Nitrates, as NO ₃	1.8	1.8
<i>Hypothetical Combinations—</i>		
Calcium carbonate	22.5	4.5
Calcium sulphate	1.7	2.1
Calcium chloride	—	0.3
Magnesium sulphate	0.4	—
Magnesium chloride	0.5	0.6
Sodium chloride	1.8	1.5
Sodium nitrate	2.5	2.5
Silica	1.5	1.5

Softening by the Zeolite or Base-Exchange Process. The development of the zeolite process of softening arose from the discovery made by J. T. Way, Chemist to the Royal Agricultural Society, in 1850, that certain mineral constituents of the soil, *i.e.*, hydrated silicates, possessed the property of base-exchange. Way also succeeded in preparing base-exchange materials from solutions of sodium silicate and aluminium sulphate, but he did not appreciate the reversibility of the process. In 1906, Gans and other German workers applied this discovery to practice and introduced for water softening purposes a synthetic hydrated silicate of aluminium and sodium called "Permutit." Since that date, the process has steadily progressed, and there are now available several groups of materials of different character and manufacture having base-exchange properties. The process is extensively used in industrial water softening, and it has also been adopted in a number of municipal softening plants in preference to the lime and lime-soda processes.

The Softening Materials. The term "zeolite," given to the materials used in base-exchange softening, was borrowed from geological nomenclature in which it referred to certain minerals which appeared to boil when heated to fusion. There are two main groups of water-softening zeolites, the siliceous and the carbonaceous. The former may either be produced synthetically from sodium silicate and sodium aluminate, or processed from natural minerals, such as Glauconite or Greensand. Fullers earth and certain clays can be treated, but they produce less satisfactory materials than Greensand. The carbonaceous zeolites are prepared by the action of sulphuric acid or sulphur trioxide on carbonaceous materials, such as coal, lignite and peat. This type of zeolite possesses the property of exchanging either sodium or hydrogen for calcium and magnesium.

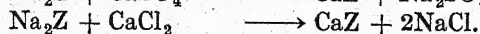
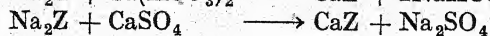
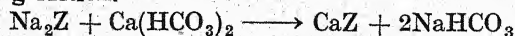
Arising from discoveries made in the Chemical Research Laboratory of the Water Pollution Research Board, another group of exchange materials known as "synthetic resins" has recently been introduced. These are condensation products of polyhydric phenols and aromatic amines with formaldehyde. Similar to the carbonaceous zeolites, the phenolic or "acidic" resins have the power of substituting hydrogen for a base, whereas the amino or "basic" resins will remove anions, or acids, from solution. By the combined use of these various exchange materials, water can be softened to any required degree, or can be almost completely demineralised, both acids and bases being removed, to leave a product resembling distilled water.

The siliceous zeolites have hitherto been employed in municipal water softening plants, but the carbonaceous products are now coming into use. The former are white-grey or brown, granular materials, whilst the latter are black in colour.

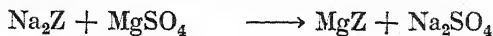
Synthetic siliceous zeolites have higher base-exchange capacities than the natural siliceous products, but they are more fragile and are detrimentally affected by free carbonic acid and small traces of impurities in water. The carbonaceous products are robust, granular solids, resistant to acids, and possess high base-exchange value equivalent to that of the synthetic siliceous zeolites.

The Softening Reactions. The exact structure of the zeolites and the reactions that take place in the softening of water are not clearly understood. When regenerated for softening use, they are regarded as the sodium compound of hydrated alumino-silicate. On coming in contact with hard water, the zeolite exchanges its sodium for the calcium and magnesium of the water, and the latter thus becomes softened. The process is reversible, and, on depletion of sodium, the zeolites can be regenerated by treatment with a solution of sodium chloride. These reactions can be represented by the following formulæ, in which Z represents the zeolite :—

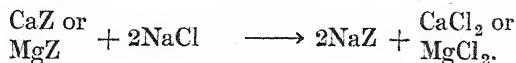
(a) Softening Action.



Magnesium salts react in a similar manner, thus :—



(b) **Regeneration.**



Assuming no loss in zeolite, the process can, therefore, be continued indefinitely by removing the accumulated calcium and magnesium from the zeolite and replenishing it with sodium at the required frequency. Common salt is, therefore, the only chemical used, and its consumption is responsible for the main running costs, other items being labour, and water wasted in regeneration and washing of the zeolite.

Loss of zeolite, either quantitative or qualitative, may be considerable if synthetic siliceous zeolites are used in unsuitable cases, but with properly designed and operated plants, particularly those employing natural siliceous and carbonaceous zeolites, the loss in material is negligible.

Base-Exchange Capacity. The base-exchange value of zeolites is usually expressed in terms of the amount of hardness, calculated as CaCO_3 or CaO , removed by 1 cubic foot of the material after regeneration with salt. It is only an approximate value which can be varied according to the method of use and the amount of salt used in regeneration. Under satisfactory normal working conditions, the natural siliceous zeolites are capable of removing approximately 3,000 grains (0.43 lb.) of hardness, as CaCO_3 , per 1 cubic foot of material.

The synthetic siliceous zeolites, which are believed to exert an internal as well as a surface action, have capacities of as high as 12,000 grains of hardness as CaCO_3 per cubic foot, but 9,000 grains (1.29 lb.) CaCO_3 , or 0.72 lb. CaO , per cubic foot, can be regarded as the average value of the best products. The weight of the materials per unit volume varies considerably, and, expressed per unit of weight, the base-exchange capacity of the synthetic zeolites is four to five times that of the natural siliceous zeolites.

In practical application the natural siliceous zeolites involve, therefore, the use of larger plants or more frequent regeneration, with consequent increase of water wastage in washing operations. They are advantageous, however, in being more durable and less susceptible to injury by the presence of free carbonic acid, metallic impurities, etc., in the water.

Salt Consumption. The salt consumption in practical base-exchange softening is two to three times the theoretical requirement (0.167 lb. NaCl per 1,000 grains of hardness as CaCO_3), owing to the fact that it is a reversible reaction, and an excess of either sodium or calcium is necessary to make it proceed in one or the other direction. Salt consumption is variable within limits according to the design and operation of the plant. It may be reduced by providing a larger amount of zeolite per unit flow of water, or *vice versa*, and running costs can thus

be reduced at the expense of capital costs. The installations are usually arranged to operate at a salt consumption of the order of 0.3 to 0.5 lb. of salt per 1,000 grains of hardness, as CaCO_3 , removed. This is sometimes expressed as a ratio of $\text{NaCl}/\text{CaCO}_3$ or NaCl/CaO , which, on the above basis, would be 2.1 : 1 to 3.5 : 1 and 3.75 : 1 to 6.25 : 1 respectively.

Assuming that it is required to soften a water supply of 1 million gallons per day from 25 to 10 parts per 100,000 of hardness as CaCO_3 , and the operating ratio of the plant is $\text{NaCl}/\text{CaCO}_3 = 2.3 : 1$ ($\text{NaCl}/\text{CaO} = 4 : 1$), the hardness to be removed is :—

$$\begin{aligned} & 15 \text{ parts per } 100,000 \\ & = 15 \text{ lb. } \text{CaCO}_3 \text{ per } 10,000 \text{ gallons} \\ & = 1,500 \text{ lb. } \text{CaCO}_3 \text{ per million gallons ;} \end{aligned}$$

and the salt consumption will be :—

$$1,500 \times 2.3 = 3,450 \text{ lb.} = 1.54 \text{ tons per day or approximately } 562 \text{ tons per annum.}$$

Operation of Plant. The softening plant consists of one or more units, resembling rapid sand filters, containing beds of zeolite, and equipped with necessary valves, meters recording total flows and rate of flow of water, etc. Provision is made for the dry storage of salt, and, preferably, also for its storage as a saturated solution (26 per cent. NaCl). Diluted brine tanks, brine pumps, and wash-water tanks are also required, and the whole should be housed.

The cycle of operations is usually downward flow of water through the zeolite beds in softening ; downward or upward flow of brine and wash-water in the process of regeneration, followed by downward flow of water for softening. With multiple identical units a sequence is conveniently arranged so that one unit at a time comes out of service for regeneration in regular order. In plants working continuously day and night, provision is, therefore, made that the full output is maintained with at least one unit out of commission.

Regeneration. Regeneration is carried out with diluted brine (5 to 10 per cent. NaCl), a sufficient volume being pumped through the zeolite bed to give the required charge of sodium. This is followed by a flow of clean water until the zeolite is washed free from excess chlorides, the wash-water being discharged to waste. The whole operation of regeneration and washing is usually completed in approximately 30 minutes per unit, and the unit is then returned to service.

Some economy in salt consumption may be obtained by employing the so-called double regeneration method. The brine is divided into two portions, one of which is passed through the exhausted zeolite first, and, becoming highly charged with chlorides of calcium and magnesium, is discharged to waste. The second portion is then passed through the zeolite, and, containing a relatively high proportion of sodium chloride, is returned to a storage tank to become the first brine charge at the succeeding regeneration, and so on.

Wash-Water and Waste. The quantity of water used in the regeneration and back-washing processes usually varies from 2 per cent. to 5 per cent. of the total water pumped into supply, according to the design of the plant, the type of zeolite, and the use of recovery methods. Towards the termination of washing after regeneration, the water contains comparatively little chlorides, and some of the water can, therefore, be recovered and utilised for preparing brine dilutions and as the first wash-water of the next unit regeneration.

The waste from the plant is a clear, colourless, excessively hard and highly saline water having a chlorine in chlorides content of approximately 1 per cent. The composition of an average sample obtained from the installation, the working details of which are given on p. 679, is shown by the following analyses:—

TABLE II
COMPOSITION OF WASTE FROM A BASE-EXCHANGE SOFTENING PLANT
Parts per 100,000

pH	7.2	<i>Hypothetical Combinations:—</i>	
Specific Gravity	1012	Calcium carbonate	20
Total Solids	1594	Calcium sulphate	5
Calcium, as Ca	320	Calcium chloride	861
Magnesium, as Mg	5.5	Magnesium chloride	22
Sodium, as Na	268	Sodium chloride	681
Carbonate, as CO ₃	12	Sodium nitrate	3
Sulphate, as SO ₄	3.2		
Chlorine, as Cl	980		
Nitrate, as NO ₃	2.5		
Silica, as SiO ₂	1.8		

Difficulty sometimes arises in the disposal of this highly saline water. Discharge into the public sewers is the most satisfactory method of disposal, and a balancing tank can be arranged in order to even-out the flow. It is permissible to discharge this waste into tidal rivers, or rivers in which the flow of water is very great in relation to that of the waste.

Control of Operations. Control of the base-exchange process is very simple. The approximate hardness of the raw water should be frequently checked by soap solution tests. The production of water of zero hardness is similarly ascertained, and the effluent from each unit should be frequently tested. A sampling tap should be fitted on the outlet main of each unit for this purpose. In the process of regeneration, it is important that the brine charge should be correct, and this is checked by specific gravity determinations (which can be made by automatic instruments) of the saturated and diluted brines. In older installations the salt charge is weighed and dissolved at each individual regeneration. The sufficiency of back-washing after regeneration is ascertained by chloride determination and also by the soap solution test, since hardness will fall to zero as the chlorides are removed. It is unnecessary, however, to continue the wash until zero hardness is

obtained, and it can be arrested, and the unit returned to service, when the hardness of the wash-water does not exceed 5 parts per 100,000. In normal working, and with a supply which does not fluctuate in character, the volume of water which the units will soften before requiring regeneration, and the volumes of brine and wash-water required, become constants, and control is then maintained almost entirely by observing flows on recording meters.

Operation of valves, etc., is usually manual, but automatic operation has been incorporated in a few installations.

Blending. The softened water discharged by the zeolite units has no hardness, all calcium and magnesium salts having been converted into the corresponding salts of sodium which have no soap-destroying or scale-forming properties. Such completely softened water is often required in industry, but is inadvisable in municipal supplies, owing to the corrosion of mains, pipes and fittings which would result. Also, zero soft water has impaired palatability, is insipid and would not be appreciated for drinking purposes. It is customary, therefore, in municipal base-exchange plants to soften a portion of the water to zero, and then mix or blend it with the other portion of unsoftened water so as to produce a final hardness of the order of 10 parts per 100,000. Thus, if two-thirds of a supply having 30 parts per 100,000 of hardness is softened to zero, and then mixed with the remaining one-third of hard water, before distribution, the consumers will receive water having 10 parts per 100,000 of hardness. Although the untreated fraction may contain some permanent hardness, the total hardness of the final blended water will react as temporary hardness, *i.e.*, will be deposited on boiling, owing to the fact that the calcium and magnesium bicarbonates of the softened fraction have been converted to sodium bicarbonate. This, for example, reacts with calcium sulphate, calcium carbonate being precipitated and sodium sulphate remaining in solution.

By adjustment of the proportions of zero soft and hard water respectively in blending, any desired degree of hardness can be obtained in the final water. Blending of zero soft and hard waters causes no visible change in the water. The correctness of blend is demonstrated by water flow recording meters and is checked by soap solution hardness tests.

The Results of Base-Exchange Softening. Since there is no precipitation of calcium or magnesium, but simply their replacement by sodium, the total solids in the water are not reduced by base-exchange softening, but may be slightly increased. For boiler and other uses, this is a disadvantage compared with lime softening in which calcium and magnesium salts are removed. The saline constituents of base-exchange softened waters consist principally of sodium salts, the bicarbonate, sulphate, and chloride, according to the concentrations of the latter in the original water. Traces of calcium and magnesium are, of course, present in the blended water of municipal supplies according to the proportion of hard water in the final mixture. Water

originally containing appreciable carbonate hardness may, after base-exchange softening, have a higher content of sodium bicarbonate than is advisable for boiler and other industrial purposes, hence, lime-soda softening is often preferable in such instances. Base-exchange softened water is often used in low-pressure boilers, when undue concentration of solids and other detrimental effects are avoided by frequent blowing down of the boilers. It is, however, objectionable for high-pressure boilers. The presence of appreciable concentrations of sodium bicarbonate causes foaming and priming, and decomposition of the bicarbonate, with the liberation of carbon dioxide and formation of caustic soda, may occur, giving rise to corrosion and caustic embrittlement. The latter can be avoided by maintaining in the feed water ratios of sodium sulphate to total alkalinity, calculated as sodium carbonate, of 1 : 1, 2 : 1 and 3 : 1 for boiler pressures of under 150 lb., 150-250 lb. and over 250 lb. per square inch respectively (see Technical Paper, No. 1, 1929, Department of Scientific and Industrial Research).

Apart from the above-mentioned change in the saline constituents, base-exchange softening causes no material alteration in a water. The water remains clear, bright and colourless, and, apart from the "flatness" of soft water, unimpaired in taste.

Base-exchange softening effects no significant organic and bacterial purification, and impure waters must, therefore, be otherwise appropriately treated.

Corrosive action may be accentuated by base-exchange softening, particularly if free carbonic acid is present in the water. Free carbonic acid should, therefore, be removed, and the removal should take place before softening, particularly when synthetic zeolite is used, otherwise the material becomes damaged and its softening capacity impaired.

Base-exchange softening does not cause plumbo-solvency, but solvent action on aluminium is increased.

TABLE III
SHOWING WORKING DETAILS OF A MUNICIPAL BASE-EXCHANGE
SOFTENING PLANT

Number of units	6
Type of zeolite	Siliceous, synthetic.
Weight of zeolite per unit	10 tons (420 cubic feet).
NaCl/CaO ratio	3.5 : 1
Quantity of water softened per day	2.5 million gallons.
Rate of filtration per unit per hour	14,000 gallons.
Quantity of water softened to zero per regeneration	110,000 gallons.
Quantity of salt used per regeneration	520 lbs.
Quantity of water used for regeneration and washing	1.2 per cent of the total water pumped.
Hardness of the raw water, as CaCO_3	24 parts per 100,000
Hardness of the blended water, as CaCO_3	11 parts per 100,000
Disposal of waste	Into sewers

Corrosive troubles can be satisfactorily restrained in municipal supplies by removing free carbonic acid and blending the softened water with an appropriate proportion of hard water.

In properly selected instances, it is a suitable process for the softening of public water supplies, and adds nothing of a harmful character to the water.

The working details of a well-designed and operated municipal base-exchange softening plant, together with analyses of the hard and softened waters, are given in Tables III and IV. This installation has been in

TABLE IV

SHOWING ANALYSES OF SAMPLES OF HARD AND SOFTENED WATER OBTAINED AT THE INSTALLATION, THE DETAILS OF WHICH ARE GIVEN IN TABLE III

Parts per 100,000.	Hard Water.	Softened Water.	
		As delivered by the Softening Plant.	Blended Water as delivered to the Consumers.
Turbidity	Clear and bright	Clear and bright	Clear and bright
Reaction, pH.	7.3	7.3	7.3
Free Carbonic Acid, CO ₂	1.6	1.6	1.4
Metals—Iron, etc.	Nil	Nil	Nil
Nitrogen in Nitrites	Nil	Nil	Nil
Nitrogen in Nitrates	0.47	0.47	0.47
Free Ammonia	0.0000	0.0000	0.0000
Albuminoid Ammonia	0.0000	0.0000	0.0000
Oxygen Absorbed from Permanganate in four hours at 27° C.	0.005	0.000	0.000
Temporary Hardness	18.0	0.0	11.0
Permanent Hardness	5.5	0.0	0.0
Total Hardness	23.5	0.0	11.0
Total Solids	29.5	31.0	30.5
Calcium	9.3	0.0	4.2
Magnesium	0.20	0.00	0.10
Sodium	0.6	11.8	7.0
Carbonates, CO ₃	12.0	12.0	12.0
Sulphates, SO ₄	1.7	1.7	1.7
Chlorides, Cl	1.4	1.4	1.4
Nitrates, NO ₃	2.2	2.2	2.2
<i>Hypothetical Combinations—</i>			
Calcium carbonate	20.0	0.0	10.5
Calcium sulphate	2.4	0.0	0.0
Calcium chloride	1.7	0.0	0.0
Magnesium carbonate	0.0	0.0	0.4
Magnesium chloride	0.4	0.0	0.0
Magnesium nitrate	0.6	0.0	0.0
Sodium carbonate	0.0	21.2	9.7
Sodium sulphate	0.0	2.5	2.5
Sodium chloride	—	2.3	2.3
Sodium nitrate	2.3	3.0	3.0
Silica	1.2	1.2	1.2

operation for more than seven years, and the inclusive cost of softening has been approximately one penny per 1,000 gallons of water distributed to the consumers. According to Porteous (1935), whose detailed account of the engineering and financial circumstances of the installation should be consulted, the capital costs of the plant amounted to £19,000, which was less than 50 per cent. of the costs of a lime-softening plant.

Selection of Process. A decision as to the selection of either the lime or base-exchange processes for the softening of municipal water supplies is governed by many considerations, of which the character of the water, the existing circumstances of the waterworks with regard to engineering lay-out and available space, and the facilities for the disposal of waste, are the most important.

Before embarking on a softening scheme it is essential that the fullest analytical data concerning the water should be available.

Hard waters, in which the hardness is largely carbonate in character and which possess acidic or corrosive properties, contain suspended matter, iron and manganese, or are organically and bacteriologically impure, are usually best softened by means of the lime process. The presence of a high sodium bicarbonate content, resulting from the base-exchange softening of a water with much carbonate hardness, contributes to corrosion of metals, particularly when free carbonic acid is also present. Also, it has disadvantages for boiler, laundry and other industrial purposes. Free carbonic acid is deleterious to synthetic zeolites, causing breakdown of the material and loss of softening capacity. Suspended matter, being retained, partially or completely, in a base-exchange softener, causes blocking of the zeolite bed, coating of the grains, and interference with softening, which is largely a surface action. Iron and manganese, whether present in the water in suspension or solution, are deleterious. These metals may, in fact, become incorporated in the zeolite and permanently impair its efficiency. Base-exchange softening effects no significant organic and bacterial purification, and polluted waters should not be softened by this process.

In all of these conditions, waters requiring softening should be treated by the lime process, or, as an alternative, appropriately treated prior to base-exchange softening. The excess-lime process for the simultaneous purification and softening of certain hard, polluted waters, has been described in Chapter XLII.

Waters which contain appreciable magnesium hardness, or have hardness in non-carbonate form, are more conveniently softened by base-exchange, since other chemicals, such as soda ash, are required in addition to lime, and the chemical precipitation process becomes complicated. In industrial practice, this process may also be the more suitable for softening water of low total hardness.

A base-exchange softening plant is often more easily added to an existing waterworks than a lime-softening plant. It requires less space, can readily be housed, and also can be inserted in a pressure system, thus avoiding the necessity for double pumping. It is a comparatively simple process, readily controllable by elementary tests and rule-of-

thumb methods, and, in fact, can be made automatic in operation. Also, it can deal satisfactorily with variations in hardness of the water.

Lime and lime-soda plants require constant, skilled attention, involve a complexity of processes, each of which must be adjusted according to fluctuations in the character of the water, and are much less flexible than base-exchange plants.

The degree of softening attainable by lime is determined by the character of the water, and cannot be prearranged or varied at will. In the base-exchange process, however, the degree of softening can be determined and altered as desired by the simple method of blending the completely softened water yielded by the plant with variable fractions of the unsoftened water.

The disposal of the voluminous sludge of a lime-softening plant is often an insuperable difficulty, whereas the liquid waste of a base-exchange plant may readily be disposed of by discharging to the public sewers or sometimes to watercourses. Occasionally, however, base-exchange softening has been impracticable owing to the absence of facilities for disposing of the highly saline waste. Some of the disadvantages of the lime process may, however, become less important as a result of the recent introduction of better design in precipitation tanks, and the improved methods previously mentioned when describing this process.

The inclusive costs (capital and running) of softening by the base-exchange process are usually less than in lime softening, particularly when the latter includes recarbonation and filtration.

The base-exchange process can be adapted to small domestic softening plants in which the lime process is usually impracticable. Since heat is detrimental, zeolite softening must not be inserted in domestic hot-water services.

Combined Processes of Treatment. 1. **Softening by Lime and Zeolite.** Lime-softening and base-exchange softening can be used in combination as an alternative to lime-soda softening, for the removal of both carbonate and non-carbonate hardness. The carbonate hardness is first reduced by the lime process, and, after removal of the suspension, the remaining hardness, which is mostly non-carbonate, is removed by base-exchange. Zero soft water, with reduced total solids and sodium bicarbonate alkalinity, is thus obtained.

2. **Softening by Siliceous Zeolite and Carbonaceous Zeolite.** Carbonaceous zeolites (and certain synthetic resins) can be used to exchange hydrogen for calcium, magnesium and sodium in water. The material is regenerated with dilute acid (sulphuric) when depleted of hydrogen, and the process proceeds, therefore, on similar lines to ordinary sodium exchange softening. The waste obtained from the wash-water after regeneration is an acid solution of calcium, magnesium and sodium sulphates (or chlorides if hydrochloric acid is used instead of sulphuric acid for regeneration).

The effect of hydrogen-ion exchange on the water is to convert its dissolved salts into the corresponding acids. Carbonates, sulphates

and chlorides are thus converted into carbonic acid, sulphuric acid and hydrochloric acid respectively, and calcium, magnesium and sodium replace hydrogen in the "zeolite." The treated water is, therefore, acid in character and cannot be used for ordinary purposes until the acids are neutralised or removed.

Removal of the carbonic acid can be effected by aeration, but other methods are required to remove the remaining acids. The possible applications of the acid water are as follows:—

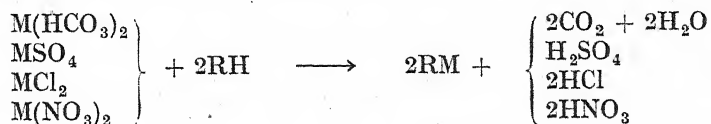
(a) It can be blended with ordinary sodium base-exchange softened water for the purpose of reducing the sodium bicarbonate alkalinity when this is unduly high. Certain waters naturally containing much sodium bicarbonate can similarly be treated. In such blending, the dilute acid in the one fraction decomposes the bicarbonates in the other, and the liberated carbon dioxide can be removed by aeration. By the combined use of the sodium exchange and hydrogen exchange processes, a water can, therefore, be obtained which approximates to a lime-soda softened water, but has zero hardness, and gives rise to no after-deposition.

(b) Blending of the acid water with lime-softened or excess-lime treated water might be used as an alternative to recarbonation for the prevention of calcium carbonate deposition.

(c) The acids can be removed from the water, such as by synthetic resins, when a condition approximating to distilled water is reached, *i.e.*, both acids and bases have been removed and the water is practically demineralised.

3. Carbonaceous Zeolites and Synthetic Resins. There are two groups of synthetic resins, *i.e.*, the phenolic or "acidic," and the amino or "basic." Similar to the carbonaceous zeolites, the former have the power of substituting hydrogen for calcium, magnesium and sodium in water, and the latter will remove acids.

These reactions can be represented as follows: RH represents the hydrogen-ion carbonaceous zeolite or phenolic resin (H = hydrogen), and M represents calcium, magnesium or sodium.



When exhausted, the base-removing material is regenerated with dilute acid (sulphuric) and the acid-removing material with dilute alkali (sodium hydroxide), when the wastes produced are acid and alkaline in reaction respectively.

By the combined use of the hydrogen-exchange process and acid removal, water can be deprived of its dissolved salts, and, apart from the possible presence of silica, it is therefore completely demineralised. By a system of blending, the saline constituents can be changed quantitatively and qualitatively as required.

These processes provide, therefore, an alternative to distillation and

also permit the removal from water of constituents such as chloride, sulphate and bicarbonate of sodium, which hitherto has been impracticable or difficult.

There are obviously great possibilities in these processes in respect of both partial and complete demineralisation of water. The latter might, for example, fulfil the requirements of modern high-pressure boilers and be used in many other industrial processes in which a water of minimal total solids content is necessary or beneficial.

According to Akeroyd (1942), who records the practical application of this system (Permutit Zeo-Karb H-ion Deminrolit Process) for the production of boiler feed water at power stations and other works, the cost of treatment is approximately sixpence per 1,000 gallons.

The application of these processes to municipal supplies is also possible, and certain waters now rejected on grounds of excessive salinity may in future be treated and rendered suitable for use.

In addition to industrial installations, there is at present at least one municipal waterworks treatment plant in which some of these processes are incorporated, *i.e.*, the Bolsovermoor Plantation Works of the Chesterfield and Bolsover Water Board (1939). The output of these works is one million gallons daily, and the system of treatment, installed in preference to lime-soda softening, is briefly as follows :—

The water, derived from a well in the Magnesian Limestone, is first treated by coagulant and rapid sand filtration to remove suspended matter. It is then divided into three portions, one of which is softened to zero by the sodium base-exchange process, and another by the hydrogen-exchange process. These two treated portions are mixed, aerated, and then blended with the third portion of the filtered water. By sodium base-exchange softening, calcium and magnesium bicarbonates and sulphates are converted into the corresponding salts of sodium. By hydrogen-ion exchange the calcium and magnesium salts are converted into the corresponding acids, and on mixing the two portions the acids are neutralised. Carbon dioxide is removed by aeration, and blending with the third portion of untreated water introduces a suitable content of solids. Partial demineralisation and softening, without leaving excess of sodium bicarbonate alkalinity, is thus obtained.

References

- AKEROYD. 1942. *Engineering and Boiler House Review*, 55, 7.
CHESTERFIELD AND BOLSOVER WATER BOARD. 1939. *Water and Water Engineering*, 41, 380.
HARWOOD. 1941. *Chemistry and Industry*, 60, 43.
PORTEOUS. 1935. "Water Softening at Cambridge," Official Circular No. 125, of the British Waterworks Association.
"Water Pollution Research," Technical Paper No. 1, 1929. "Water Softening. The Base-Exchange or Zeolite Process." H.M. Stationery Office, London.

CHAPTER XLIV

IRON AND MANGANESE IN WATER

Occurrence of Iron. Iron is one of the most important and valuable of all the elements. It is essential for the nutrition and healthy development of most plants and animals, and also of man, and is very widely distributed in nature. Iron is present in practically all soils, gravels, sands and rocks, sometimes in considerable amount, but often only in small traces. It is usually found in the form of oxides, common varieties of which include red hæmatite, ferric oxide, Fe_2O_3 , brown hæmatite, hydrated iron oxide, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$, and magnetic oxide of iron, Fe_3O_4 . Other common forms are ferrous carbonate, FeCO_3 , and the sulphide, FeS_2 , known as iron pyrites. Rain, in percolating through soils and rocks, acquires iron in addition to other mineral constituents according to the character of the geological formation, and there are very few waters, whether from surface or deep sources, which do not contain at least small traces of iron. Occasionally the amount of iron is excessive, when the waters are described as "chalybeate." Manganese, usually in smaller amounts, may accompany iron in water.

Many deep wells and boreholes in the cretaceous water-bearing formations such as the Chalk, Greensand, Hastings and Tunbridge Wells Beds, etc., yield slightly ferruginous waters which require treatment to render them suitable for public supply purposes, and examples are shown in Table I.

Iron is usually dissolved in the form of ferrous bicarbonate, but, in some instances, mostly ground or surface waters, it may be found as higher oxides, in complex organic combinations, or, in rare instances, as the sulphide. In waters containing traces of sulphuric acid, which may be derived from the atmosphere in industrial areas, or by pollution with trade wastes, iron may be present as ferrous and ferric sulphate.

The exposure of water to air results in the oxidation of soluble ferrous bicarbonate to insoluble or colloidal ferric hydroxide. The water thus becomes opalescent and discoloured, and a deposit finally forms which undergoes further oxidation. In the oxidation of ferrous bicarbonate, carbon dioxide is released and again becomes available for further iron-dissolving action. This reaction can be represented as follows: $4\text{Fe}(\text{HCO}_3)_2 + \text{O}_2 + 2\text{H}_2\text{O} = 4\text{Fe}(\text{OH})_3 + 8\text{CO}_2$.

Waters which have been exposed to the atmosphere are frequently found, therefore, to contain iron, part of which is in solution and part in suspension. When drawn from an underground source, the water may initially be clear and bright, but after a short period of time, opalescence or deposit, due to oxidation of the soluble salt to the insoluble form, occurs. Thus, by the time a sample is received at the

TABLE I
SHOWING EXAMPLES OF FERRUGINOUS WATERS
(Parts per 100,000)

District	Source of Water	Iron (Fe)	Manganese(Mn)
Sussex	Hastings beds	4.8	0.20
"	" "	3.4	0.46
"	" "	1.7	0.03
"	" "	0.20	0.09
"	" "	0.20	0.08
Kent	" "	0.20	0.06
"	" "	0.80	0.38
"	Lower greensand	0.45	Absent
Bedfordshire	Greensand	1.7	0.02
Essex	Tertiary, gravels	1.6	Absent
"	Chalk	1.2	Absent
Suffolk	"	0.5	Absent
"	"	0.29	Absent
Hampshire	"	0.24	Absent
West Riding, Yorkshire	Coal measures	0.50	0.44
" " " " " "	Moorland surface	0.06	0.04
North Riding, Yorkshire	Lias	0.05	0.07
Lancashire	New red sandstone	0.35	0.04
Staffordshire	" " " "	0.08	0.07
Derbyshire	Triassic-Bunter sandstone	0.26	0.04

laboratory for analysis, the iron which was originally in solution may be almost entirely precipitated.

Objections to Iron and Manganese in Water. The presence of iron and manganese in water is objectionable owing to the production of discoloration, turbidity, deposit and taste. Ferruginous waters have an astringent or bitter taste, and, by combination of the iron with tannin, impart an inky colour to tea infusions. Water in streams, ponds and wells may similarly acquire an inky colour owing to the combination of iron and tannin, the latter being derived from roots or the droppings of trees, particularly oaks.

Water containing iron and manganese is undesirable for culinary use, causing brown-coloured deposition on vegetables during washing and cooking. It is also objectionable for laundry purposes and gives rise to "iron-moulding" of linen and other fabrics being washed.

For many industrial purposes such as paper-making, dyeing, photographic film manufacture and ice-making, the water must be entirely free from iron and manganese.

Even small traces of iron and manganese in water lead to the accumulation of appreciable deposits in distribution mains and reservoirs, and these often prove troublesome to the water authority and objectionable to consumers. Under such conditions, growths of iron bacteria often develop in the distribution system, when difficulties such as blocking of mains, meters, pipes, etc., are accentuated, and complaints of discoloured, turbid and unpalatable water become more

serious. Sulphide of iron and sulphuretted hydrogen may also be produced, when the water drawn from taps emits an offensive odour which consumers often associate with sewage.

Inconvenience may arise from the presence in public water supplies of such small traces of iron and manganese as 0.03 part per 100,000, and, when the amount exceeds 0.04 part per 100,000, the installation of treatment plant is usually advisable.

Iron may originally be present in a water as derived from the source or be acquired from metals with which the water subsequently comes in contact. To decide this important point it is necessary to examine samples collected directly from the source. If the latter is a deep well or borehole and samples can only be obtained from the pump delivery, a series of samples should be collected at intervals throughout several hours' continuous pumping at maximum capacity. Should the examination of these samples show that the amount of iron present in the water decreases rapidly as pumping proceeds, it is fairly certain that some, if not all, of the iron is derived from the metals of the borehole tubing, rising main, etc.

Water which is free from iron at its source usually acquires a minute trace from the mains and pipes through which it is distributed to the consumers. It is rare, therefore, that samples collected from taps off service mains are quite free from iron, and unobjectionable traces of the order of 0.005 to 0.02 part per 100,000 are usually found. All waters have some action on metals, but if, during distribution, a water acquires more than the above traces of iron, and objections of turbidity, discoloration, etc. arise, preventive measures are necessary. (For further information with regard to the treatment of corrosive and plumbo-solvent waters the reader is referred to Chapter XLV.)

Ferruginous deposits gradually accumulate in most water mains, and periodical main-flushing, particularly of "dead-ends," is advisable. The presence of much loosely-adherent "rust" in mains leads to the supply of ferruginous water to the consumers, with the usual complaints of discoloration, turbidity, deposit, impaired palatability, etc. These complaints may be intermittent and arise when changes occur in the velocity, pressure or direction of flow of the water in the mains. Considerable deposits may accumulate in reservoirs and mains from water which originally contained only a small trace of iron. The development of growths of iron bacteria is always to be anticipated in waters containing iron, particularly when organic matter is also present, and such growths accentuate the deposits and aggravate the complaints. When manganese is associated with the iron, the colour of these deposits is often black rather than brown.

Methods of Treatment. Troubles due to iron and manganese are, therefore, avoided by: (1) treatment of the water before distribution, if it contains more than the minutest traces of iron and manganese, or if it is unduly corrosive to metals; (2) protection of mains by bituminous linings, or the use of specially selected mains, such as asbestos-cement tubes; (3) avoidance of "dead-end" mains; (4) avoidance of disturbances in mains; (5) periodical flushing of mains.

In some trade or technical processes in which it is essential to have water absolutely free from iron, it is customary to install special filters in the factories for the treatment of the water. Although the public water supply may be entirely suitable for drinking, domestic and ordinary purposes, it is practically impossible to deliver it to consumers free from the minutest traces of iron.

The processes employed at waterworks for the purification of water, such as storage, coagulation and filtration, satisfactorily remove the small traces of iron which are present in most waters.

The lime process of softening is also very effective in removing iron from water. This process is, therefore, particularly valuable for the removal of free carbonic acid, iron and hardness from certain hard, ferruginous waters, such as those which are yielded by many wells in the Chalk in East Anglia. Base-exchange softening plants also remove traces of iron from water, but iron is deleterious to synthetic zeolites, and if present in significant trace it should be removed prior to softening by the base-exchange process.

There are many instances in which waters require treatment solely for the removal of iron and manganese. This removal is sometimes effected by simple measures such as aeration, with or without sedimentation, followed by filtration, but more complicated treatment, including the use of chemicals, is often required. A decision as to the method of treatment to be employed is influenced by the state of combination in which the metals are contained in the water, and the character of the water in respect of its gaseous, mineral, organic and biological constituents. Each case must be individually considered, adequate analyses made, and experimental treatment carried out before the most suitable method can be decided.

When the question of iron removal is under consideration, it is important to decide what other treatment of the water, if any, is necessary or desirable. It is, for example, inadvisable to remove the iron yet leave sufficient free carbonic acid to cause corrosion of mains and pipes, and the presence of considerable free carbonic acid is usual in ferruginous waters. Also, if the water contains considerable temporary hardness, the merits of lime-softening should be carefully considered, since this process would simultaneously remove free carbonic acid, iron and hardness. The water may also require organic and bacterial purification, for which suitable measures may be combined with those required for the removal of iron. Chlorination can, for example, be employed to assist removal of iron and manganese, and, at the same time, obtain bacterial purification. The possible presence of manganese in association with iron must be ascertained, since it demands special measures for its removal. Manganese is not oxidised and precipitated so readily as iron, and, if suitable precautions are not observed, the treatment may remove the iron, but allow the manganese to remain in the water and produce deposits in mains, reservoirs, etc.

The means by which iron and manganese are removed from water consist substantially of their precipitation by oxidation and removal of

free carbonic acid, followed by separation of the suspension by sedimentation and/or filtration. Aeration may suffice for the preliminary precipitation, but, when the amounts of free carbonic acid and iron are high, or relatively soluble compounds of iron or manganese are present, the addition of chemicals is necessary. Sedimentation tanks, for the removal of the bulk of the precipitate prior to filtration, are usually required when the amount of iron in the water is high or manganese is present. Filters will become overloaded and impossible to operate efficiently if fed with unduly turbid water. The design of the tanks must receive careful consideration, for, if their capacities are inadequate and the bulk of the precipitate is not removed, the aforementioned interference with filtration will result.

Aeration. Open aeration, in which the water is projected, splashed or sprayed into the atmosphere, is a simple and economical process in which free carbonic acid is dissipated, and iron oxidised and precipitated from solution. It also dissipates sulphuretted hydrogen which is not infrequently present in ferruginous waters. Closed aeration is sometimes employed in pressure systems, but is less effective. Aeration may not suffice to obtain adequate removal of free carbonic acid and precipitation of iron, and it is seldom effective when manganese is also present in the water. It is worthy of application, however, as a preliminary to the addition of chemicals, since it increases efficiency of treatment and economises in consumption of lime, etc.

Under certain conditions, aeration, followed immediately by filtration, provides sufficient treatment. Rapid or mechanical filters are usually employed in such cases and the filters often contain special iron-removing media, such as "Polarite," "Birm," or selected zeolite sands, in addition to ordinary filter sand. The results which can be obtained in an installation of this character are shown in Table II.

TABLE II
SHOWING RESULTS OF TREATMENT FOR IRON REMOVAL BY CANDY'S
POLARITE FILTERS

Parts per 100,000.	Time when Sample was taken.					
	9 a.m.	10 a.m.	11 a.m.	2 p.m.	3 p.m.	4 p.m.
1. Fe in untreated water .	.320	—	—	.150	—	—
" filtered water .	.002	.005	.003	.002	.004	.002
2. " untreated water .	.140	—	—	.160	—	—
" filtered water .	< .002	.008	.007	.005	.005	< .002
3. " untreated water .	—	.200	—	.020	—	—
" filtered water .	.002	.007	.010	.005	.004	.004
4. " untreated water .	.014	—	—	.26	—	—
" filtered water .	.005	.01	.008	.005	.008	.008
5. " untreated water .	.92	—	—	.181	—	—
" filtered water .	< .002	.006	.008	.002	.003	.002
6. " untreated water .	.55	—	—	.094	—	—
" filtered water .	< .002	.004	.012	.002	< .002	.003
7. " untreated water .	—	.70	—	.11	—	—
" filtered water .	.004	.002	.026	< .002	.002	< .002
8. " untreated water .	.55	—	—	.120	—	—
" filtered water .	.002	.008	< .002	< .002	< .002	< .002

In certain instances, the use of slow sand filters is justified and may yield satisfactory results, but they cannot be effectively used for the removal of large amounts of iron and manganese from waters, owing to rapid clogging. Sedimentation in tanks, followed by rapid filtration, is required in such cases.

When it is required to remove only small traces of iron and manganese, and when experiments have shown that these are readily precipitated from the water, rapid filters can be inserted in a pressure system. It is possible in such cases to inject air to assist in the precipitation of the iron prior to filtration of the water, or, when the free carbonic acid content of the water is high and the pH value low (causing apprehension of corrosive troubles), lime can similarly be injected. Materials such as "Polarite" assist removal of iron by oxidation and catalytic action.

Filters often increase in efficiency owing to the incrustation of the grains of the medium with higher oxides of iron and manganese which act as catalysts. The development of biological growths, including the so-called iron and manganese bacteria, on the surface layers of slow sand filters, also plays an important part in the removal of iron and manganese by such units.

Chemical Treatment. Lime is the most efficient and economical chemical for use in the removal of free carbonic acid, iron and manganese, particularly when preceded by aeration. It should be applied in such dose that the final pH of the water, after settlement and filtration, is in the 7.5 to 8.5 range, and thorough mixing of lime and water should take place. Adequate sedimentation of the precipitate may take several hours, particularly when manganese is present, and flocculation and deposition may sometimes be accelerated by the use of aluminium sulphate or sodium aluminate. The sedimentation tanks must, of course, be provided with facilities for desludging. Chlorination can be employed to control growths of iron bacteria in the treatment plant, if these prove troublesome, but such difficulties are usually avoided if the lime dosage is maintained at a sufficiently high level. The supernatant water run off from the sedimentation tanks to the filters should be almost clear, since good chemical treatment and sedimentation yield the best filtration results in respect of the quality of the final water and operational economy.

The installation of automatic pH recorders greatly assists in the control of treatment.

Sodium carbonate and sodium hydroxide are sometimes used for the removal of free carbonic acid, but neither is as efficient and economical as lime. Unless carefully controlled, the addition of alkalis causes calcium carbonate incrustation in pumps, meters, pipes, etc., through which the treated water flows.

The results obtained in the treatment of a water containing iron and manganese, derived from the Hastings Beds, and used for public supply purposes, are shown in Table III. Treatment consists of (a) aeration; (b) addition of lime in an average dose of 6 parts per

100,000 ; (c) sedimentation for fourteen hours ; and (d) rapid sand filtration.

TABLE III
SHOWING RESULTS OF TREATMENT FOR REMOVAL OF IRON AND MANGANESE
FROM WATER
PARTS PER 100,000

	Raw.				Treated.			
	pH.	Free CO ₂	Iron.	Man- ganese.	pH.	Free CO ₂	Iron.	Man- ganese.
1	6.2	5.7	2.3	0.74	8.0	Nil	Nil	Nil
2	6.2	5.5	2.2	0.82	8.0	Nil	Nil	Nil
3	6.3	5.8	1.72	0.75	7.8	0.2	Nil	Nil
4	6.3	5.4	1.95	0.80	8.0	0.1	Nil	Nil
5	6.3	5.5	2.7	0.82	7.8	0.2	Nil	Nil
6	6.3	5.4	2.5	0.60	7.8	0.2	Nil	Nil
7	6.4	5.0	1.95	0.57	7.6	0.3	Nil	Nil
8	6.3	5.5	2.61	0.43	9.0	Nil	Nil	Nil
9	6.2	5.8	2.21	0.55	7.8	0.2	Nil	Nil
10	6.4	5.4	2.64	0.49	7.8	0.2	Nil	Nil
11	6.4	5.5	2.20	0.61	8.5	Nil	Nil	Nil
12	6.2	5.6	2.39	0.50	8.0	Nil	Nil	Nil
13	6.4	6.1	2.48	0.50	8.0	Nil	Nil	Nil
14	6.3	5.5	2.07	0.49	8.0	Nil	Nil	Nil
15	6.2	5.7	2.04	0.51	7.8	0.2	Nil	Nil
16	6.4	5.4	2.42	0.57	8.0	Nil	Nil	Nil
	All opalescent with deposit				All clear and bright			

Contact Beds. Trickling filters or contact beds, containing such media as coke, clinker, stones or slag, for the aeration of water and removal of iron, are sometimes used in industrial water supplies, but find no favour in this country for the treatment of municipal supplies.

Zeolites. As previously mentioned, siliceous zeolites used for the softening of water are not satisfactorily employed for the removal of iron and manganese, but a special "manganese zeolite" was introduced for the removal of small traces of iron and manganese from water. The water is passed through a bed of the material in the same manner as in base-exchange softening, and, when the zeolite becomes exhausted, it is back-washed to remove deposit, and regenerated by passing through it a solution of permanganate of sodium or potassium. Carbonaceous zeolite can be successfully used for the simultaneous softening of water and removal of small traces of dissolved iron.

Small carbon, or silico-carbon, tap or domestic filters can be obtained for household use to remove iron from water. They should be thoroughly cleaned at intervals in order to maintain their efficiency.

Typical results obtained in the examination of waterworks treatment plant for the removal of iron and manganese are shown in Table IV.

TABLE IV
SHOWING RESULTS OBTAINED BY WATERWORKS INSTALLATIONS FOR THE REMOVAL OF IRON AND MANGANESE FROM WATER
Parts per 100,000

No.	pH	Free CO ₂	Untreated water		Total Solids	Total Hardness (as CaCO ₃)	Total Alkalinity (as CaCO ₃)	Treatment	Iron (Fe)	Manganese (Mn)
			Iron (Fe)	Manganese (Mn)					Treated Water	
1	6.6	4.8	0.42	0.04	25.0	5.5	11.5	Aeration, lime, sodium aluminate, filtration	Absent	Absent
2	7.4	2.8	0.17	Absent	61.0	—	37.0	Lime, sodium aluminate, filtration	Absent	—
3	6.5	3.1	0.14	0.05	17.0	5.5	—	Lime, ferrous sulphate, filtration .	Absent	Absent
4	6.7	3.5	0.32	0.04	21.0	3.0	12.5	Aeration, lime, sodium aluminate, sulphate of alumina, filtration .	Absent	Absent
5	6.3	10.0	1.05	0.20	19.0	7.0	8.0	Aeration, lime, sodium aluminate, filtration	Absent	Absent
6	6.7	3.3	0.85	0.07	16.5	10.5	10.0	Sodium aluminate, filtration .	Absent	Absent

CHAPTER XLV

CORROSION AND PLUMBO-SOLVENCY

THE corrosive and solvent action on metals exerted by water gives rise to difficulties which are among the most frequent and troublesome affecting public water supplies. Also, several factors are variously implicated in corrosive processes, and, since the respective parts played by each factor and the reactions taking place are not clearly understood, the difficulties are not always anticipated nor readily overcome.

From a careful consideration of adequate analyses and laboratory tests, it is possible, however, in many cases, to predict with reasonable accuracy the corrosive action and plumbo-solvency which a water will exert. Some of the methods employed to assess plumbo-solvency of waters have been described in Chapter XXI.

The metals chiefly concerned with corrosion are iron and steel, of which water mains and pipes are usually composed, and the results of such corrosion are apparent and troublesome to both the water authority and the consumer. The mains become damaged by the development of incrustation, with subsequent reduction in their carrying capacity and pitting leading to perforation, whilst consumers receive water rendered turbid and discoloured by the presence of an excess of iron.

The galvanising of iron and steel pipes does not withstand the action of aggressive waters, and, in course of time, the zinc becomes pierced or stripped, thus exposing bare steel or iron to attack. In the first stage, the water has opalescence and greyish, granular deposit due to the presence of zinc derived from the galvanising, but later, brown discoloration, turbidity and deposit arise owing to the presence of iron.

Other common metals or alloys which may be attacked are copper, bronze and brass of pipes and fittings, the presence of copper in water being manifested by the green staining of wash-basins, baths, sponges, etc., which takes place when the water comes in contact with soap or other alkaline material.

Plumbo-solvency is not demonstrated by any visible change in the water and often occurs without detection. It is revealed by the onset of plumbism among the consumers, or by the presence of lead in samples of the water.

Protection of Mains and Pipes. The methods by which the aggressive action of water on metals is restrained in order to avoid the above difficulties can be divided into two groups, *i.e.*, those applied to the metals, and those applied to the water. With regard to the former, careful consideration should be given by the engineer as to the types of mains and pipes most suitable for the particular water. In some cases,

a thin internal coating, consisting of Angus Smith's solution or other bituminous material, applied to the mains suffices to protect the metal from corrosion, but, in other cases, a thick bituminous lining is required. Cement-lined metal pipes, or asbestos-cement pipes which include no iron or steel, are sometimes used to convey water known to be corrosive.

Smaller iron and steel pipes used for domestic services are often galvanised, the zinc coating being intended to restrain corrosion until a protective carbonate film has developed on the surface of the metal. In some cases, however, waters do not provide this protective carbonate film, but, on the contrary, remove the galvanising and attack the iron or steel. In such instances, copper tubing is sometimes substituted for iron or steel pipes, since copper is a more resistant metal. Lead piping may sometimes be used as a substitute for iron or steel, but care must be exercised in such a selection, since some waters which are aggressive to iron and steel are also plumbo-solvent. Waters which possess plumbo-solvent properties are invariably aggressive to iron and steel, but some waters which attack the latter metals are not plumbo-solvent. Action on lead may take place in both hot and cold domestic systems and sometimes is more marked in the former. Asbestos-cement pipes are not available for domestic services, since they are not made in sizes of less than $1\frac{1}{2}$ inches diameter and their "plumbing" presents difficulties.

There is scope for improvements in the manufacture of mains, pipes, cisterns, etc., in order to avoid contact of water with metals, and it may be possible that developments in the plastics industry will lead to the use of such materials for this purpose. Economic considerations prevent the use of such corrosion-resisting materials as stainless steel and Monel metal for water-carrying purposes. Tin-lined pipes have been used in a few instances but have not proved satisfactory. Rubber-lined steel tubes have also been suggested for the lining of boreholes which yield aggressive waters, but the problem of preventing corrosion of tubes, pumps, etc., installed underground in boreholes and wells, has not yet been completely solved.

The available measures for the protection of mains and pipes, though often adequate, do not always suffice to avoid corrosion difficulties, and special consideration must then be given to preventive treatment of the water before its discharge to the distribution system.

Factors Concerned with Corrosion. The factors concerned in corrosive processes are variable, according to the character of the water and the conditions under which it comes in contact with metals. The following are the chief factors:—

1. *Oxygen.* This gas is dissolved in varying amount in the majority of waters, and it is implicated in the degradation of metals, oxides, together with basic carbonates, being formed in most instances of corrosion. Oxygen is, however, common to both corrosive and non-corrosive waters, and, under ordinary conditions, is not the sole or primary cause of aggressive action. Aeration, in which oxygen is introduced into water and carbon dioxide dissipated, is, in fact, often employed for the prevention of corrosion." On the other hand, deoxy-

genation is sometimes employed in the treatment of high pressure boiler feed-water in which oxygen is the sole remaining corrosive agent.

Both aerobic and anaerobic corrosion can be recognised, and the latter, which will be mentioned later, is often associated with reduction of sulphates and the presence of sulphuretted hydrogen.

2. *Acidity.* This is the most important factor in corrosion, and waters which have low pH value due to the presence of carbonic acid, or other acids, are invariably corrosive. Those in which the acidity is due to peaty and other organic acids, or to bicarbonate deficiency, are, in addition, plumbo-solvent.

3. *Alkalinity.* This also is important, and the presence in water of a sufficiency of calcium bicarbonate alkalinity, in relation to free carbon dioxide and other constituents, is, in fact, the usual determining factor in avoiding corrosion and plumbo-solvency.

4. *Mineral and Organic Constituents.* Corrosion may be accentuated by the presence in water of high total solids. Calcium and magnesium chlorides are particularly active in hot-water systems. Nitrates play some part, probably a secondary one, in corrosion processes, and high ammonia contents are objectionable in boiler feed-waters. Organic matter, such as peat extractives, has considerable importance in plumbo-solvent waters and in anti-corrosion treatment processes. In its decomposition, organic matter also plays a part in anaerobic corrosion, such as that occurring on the exterior of water mains in certain soils.

5. *Chlorination.* The presence of free chlorine or chloramines accentuates the activity of a corrosive water, or it may determine the onset of corrosion by a water which, if unchlorinated, would cause no troubles.

6. *Electrical Currents.* Corrosion may be set up by galvanic action arising from the union of dissimilar metals, or by the earthing of electrical systems to water pipes.

7. *Biological Action.* Growths of iron-bacteria and sulphur-bacteria play a part in aerobic and anaerobic corrosion respectively. The former flourish in waters containing iron, and accentuate the deposits and tubercular incrustations in corroded mains. The latter reduce sulphates and produce sulphuretted hydrogen, thus leading to the formation of reduced or ferrous salts which, being soluble, are dissolved by water to be precipitated later when the water acquires oxygen.

Factors 2 and 3 are closely inter-related and are involved in the majority of instances of corrosion and plumbo-solvency. The importance of calcium bicarbonate, and of the capacity of water to deposit a film of calcium carbonate and thus protect the metal surfaces with which it comes in contact, have long been recognised. Much attention has, therefore, been given to this consideration, particularly by American workers, notably Baylis (1935) and Langelier (1936), whose work has been directed to the development of methods for the detection of corrosive waters and the control of anti-corrosion treatment.

Waters can be classified in three groups according to their behaviour when placed in contact with calcium carbonate, as follows :—

(a) Waters which deposit calcium carbonate. These are super-saturated with calcium carbonate.

(b) Waters which dissolve calcium carbonate. These are under-saturated with calcium carbonate.

(c) Waters which are "balanced," *i.e.*, they neither dissolve nor deposit calcium carbonate when placed in contact with that substance. These are saturated with calcium carbonate and are said to be "in equilibrium."

Waters of group (a) will have a tendency to form a carbonate deposit on metal surfaces and they will not be corrosive. In certain instances, such as in lime-softened waters, the deposition of calcium carbonate in mains, etc., may be excessive and require preventive treatment (see Chapter XLIII). Those waters which give rise to only the slightest deposit of calcium carbonate are the most suitable in respect of the distribution systems of public water supplies.

Waters of groups (b) and (c) produce no protective coating in mains and pipes and, hence, distinct corrosion and slight corrosion respectively takes place.

The deposition of calcium carbonate, or otherwise, by water when placed in contact with calcium carbonate (or metals) depends on the degree with which it is already saturated with calcium carbonate. Calcium carbonate is dissolved in water in small trace as the normal carbonate, but mostly by combination with carbon dioxide, forming the bicarbonate. The system is, however, unstable, and carbon dioxide may be released, causing the precipitation of the insoluble calcium carbonate. The solubility of calcium carbonate in water is variable according to the temperature, the free carbon dioxide content, the *pH*, and the concentration of other salts present in the water. The saturation point is not, therefore, the same in all waters, nor is it constant at all times in any particular water. For example, loss of free carbon dioxide by exposure of the water to air, causing an increase in *pH*, lowers the saturation point and induces precipitation of calcium carbonate.

A water which is supersaturated with calcium carbonate, under the conditions of *pH*, etc. with which it is in contact with metals, will deposit carbonate and not corrode, whereas a water which is under-saturated will dissolve carbonate and be corrosive.

The frequent object of anti-corrosion treatment of water is, therefore, the production of slight calcium carbonate supersaturation, and this can be achieved by removing free carbon dioxide and/or increasing the calcium bicarbonate content by the addition of lime.

The method of assessment and control of corrosion, developed by Baylis, was based on the "calcium carbonate saturation test." In this test, portions of water are examined for *pH*, free carbon dioxide and alkalinity. Other portions of the water are kept in contact with an excess of pure, finely-divided chalk, when, after allowing it to stand for sufficient time to become stabilised, the above determinations are repeated. The corrosive tendency of the water is then assessed accord-

ing to the results of these two series of examinations. If, after contact with chalk, the water shows a fall in pH and in the calcium bicarbonate content, indicating a tendency to deposit calcium carbonate, it will not be corrosive. If, on the other hand, there is a rise in pH , increase in the calcium bicarbonate content and a fall in the free carbon dioxide, indicating a tendency to dissolve calcium carbonate, the water will be corrosive. If there is no change in the results after it has been in contact with calcium carbonate, the water can be described as "balanced."

Based on the results of water analysis, Langelier derived mathematically a formula which gives similar information.

The pH , free carbon dioxide, calcium, and bicarbonate contents of a water are inter-related, and, together with the total saline constituents, determine whether the water will dissolve or deposit calcium carbonate. The Langelier Index of Corrosion is based on these figures, and can be regarded as expressing the difference between the pH of the actual water and the theoretical pH which it would possess if it were in a "balanced" condition. The latter pH is referred to as pH_s . A negative index (pH of actual water lower than theoretical pH of "balanced" water) indicates that the water will be corrosive, whilst a positive index indicates that the water has a tendency to deposit calcium carbonate, and, therefore, will be non-corrosive.

In the same manner as pH does not measure the total acidity or alkalinity of a liquid, so the Langelier Index does not measure the extent to which a water will deposit calcium carbonate or be corrosive. Also, it is not a proportional measure of the amount of treatment or correction necessary to prevent corrosion. It does, however, indicate broadly the probable behaviour of a water when in contact with metals, and, by reference to a number of waters of which the action on metals was known from actual experience, the conclusions were reached that:—

1. Waters having a slightly positive index do not deposit excessive calcium carbonate and are non-corrosive.
2. Waters in which the index is zero have a tendency to corrode.
3. Waters which have a negative index are distinctly corrosive.

Langelier's Index is not strictly applicable to all raw waters, since it is concerned only with inorganic constituents, whereas the acid-organic constituents of peaty waters are highly important factors in the corrosion and plumbo-solvency exerted by such waters.

In the majority of instances, waters are aggressive to metals owing to a deficiency of calcium bicarbonate, an excessive amount of carbon dioxide, or a combination of these two factors. The effect of this deficiency or excess, as the case may be, is aggravated by organic impurity or high salinity of the water.

Classification of Corrosive Waters. In our experience, the majority of plumbo-solvent and corrosive waters possess definite characteristics according to which they can be arranged in five groups as shown in Table I.

It is convenient to describe the problems of anti-corrosion treatment

TABLE I
CLASSIFICATION AND CHARACTERISTICS OF CORROSIVE WATERS
(*Chemical Results expressed in parts per 100,000*)

Group No.	1	2	3	4	5
Common Sources	Upland and Moorland Surface Sources	Wells, usually Shallow, in Gravels and Sands	Boreholes in Iron-bearing Formations	Boreholes in Chalk, Limestone, etc.	Boreholes in London Basin and Lower Greensand
pH					
Acid :	7.0 to 4.5				
Neutral :	7.0 to 7.2				
Alkaline :	7.2 to 8.2				
FREE CARBON DIOXIDE					
Low :	0.5 or less				
Moderate :	0.5 to 3.0				
High :	4.0 or more				
BICARBONATE ALKALINITY					
Low :	3.0 or less				
Moderate :	5.0 to 20.0				
High :	25.0 or more				
TOTAL HARDNESS					
Low :	5.0 or less				
Moderate :	5.0 to 20.0				
High :	30.0 or more				
TEMPORARY HARDNESS					
Low :	3.0 or less				
Moderate :	5.0 to 20.0				
High :	25.0 or more				
PERMANENT HARDNESS					
Low :	2.0 or less				
Moderate :	3.0 to 7.0				
High :	10.0 or more				
TOTAL SOLIDS					
Low :	10.0 or less				
Moderate :	15.0 to 40.0				
High :	50.0 or more				
	Acid	Acid	Acid	Neutral or Acid	Alkaline
	Moderate or Low	Moderate or High	High	High	Moderate or Low
	Low	Low	Moderate	Moderate or High	High
	Low	Moderate or High	Moderate	Moderate or High	Moderate or Low
	Low	Low	Moderate	Moderate or High	Moderate or Low
	Low	Moderate or High	Low	Moderate or Low	Nil
	Low	Moderate or High	Moderate	Moderate or High	High

by reference to Table I, since, although there are certain features which are common to the several processes, treatment varies according to the particular characteristics of the water in question.

Group 1. The waters of this group are derived from upland or moorland surface sources, and they are both plumbo-solvent and aggressive to common metals, such as iron and steel. They are characterised by low *pH*, low or moderate free carbon dioxide,¹ low contents of calcium, bicarbonate and total solids, and the presence of vegetable or peaty organic matter often associated with high degrees of colour.

The acid-organic constituents of these waters play an important part in the corrosion processes. In their treatment it does not suffice merely to add alkali to neutralise the acidity, but the organic matter must first be removed. A water retaining its peaty organic matter will be more aggressive to metals than a water chemically identical but organically pure.

The correct anti-corrosion treatment of these waters consists, therefore, in organic purification by coagulation, settlement and filtration, followed by the addition of lime to neutralise the acidity and increase the bicarbonate alkalinity. The latter treatment should be arranged and controlled so that the final water has a slight tendency to deposit calcium carbonate and so protect metal surfaces. The use of other alkalies, such as soda ash or sodium silicate, instead of lime, which is not infrequent on account of their greater ease of application, is usually much less satisfactory in the prevention of plumbo-solvency and corrosion. Whenever practicable, alkalisation by lime is, therefore, recommended. The view, based on laboratory experiments, that waters treated with sodium silicate will deposit a protective coating of silica on lead and other metal surfaces, thereby preventing solvent and corrosive action, has not been substantiated by practical experience. In several large-scale trials we have found that sodium silicate treatment yielded less satisfactory results than the administration of lime, besides being more costly.

The addition of soda ash merely corrects acidity and does not introduce calcium bicarbonate. It encourages the deposition of calcium carbonate if calcium is present, but often waters of this group contain so little calcium bicarbonate that an increase in this constituent is required, a minimum of approximately 3 parts per 100,000 being desirable. In the treatment of waters of this group, one of the chief difficulties is, in fact, the introduction of sufficient calcium bicarbonate, since there is often inadequate free carbon dioxide present in the water to combine with the lime added to produce the desired final calcium bicarbonate alkalinity. Care must be exercised to avoid an excess of lime, since such excess tends to remove the calcium bicarbonate which has been formed.

¹ In the determination of this figure by the usual titration method, both carbon dioxide and the acid-organic matter present in this type of water are included. The result is, therefore, more correctly described as "Total Acidity" than as "Free Carbon Dioxide."

In selecting the coagulants for the organic purification of the water, it is advisable to employ those which produce a minimum of acidity, and also conserve such bicarbonate alkalinity as is present in the water. Heavy doses of aluminium sulphate will, for example, convert bicarbonate to sulphate, and cause an increase in acidity, with the possible loss of carbon dioxide by release to the atmosphere. The use of powdered chalk in conjunction with aluminium sulphate or sodium aluminate avoids such results, and chalk, in addition to increasing the bicarbonate content of the water, has the advantages of improving flocculation and organic purification.

For the efficient correction of plumbo-solvent and corrosive properties of the soft, acid, coloured, peaty waters, it is necessary first to remove the colouring organic matter and then to add a sufficient, but not excessive, dose of lime. The latter is usually small, of the order of 1.0 part per 100,000, and hence, hydrated lime can conveniently be used. The appropriate final *pH* having been determined by laboratory tests, control of treatment can be maintained at the works by indicator solution *pH* tests, or automatic *pH* recorders.

The addition of lime or other alkali as the sole treatment of waters of the character referred to in this section, is seldom satisfactory. The ultimate result is often an increase in the colour of the water, the formation of turbidity or deposit, and little, if any, restriction of plumbo-solvency and corrosion of iron and steel.

The *pH* of the water may be temporarily raised, but it is unstable in the presence of organic matter, and, hence, reverts to its original level by the time the water has passed through the distribution system.

Group 2. The waters included in this group are characterised by low *pH*, low bicarbonate alkalinity, and high total hardness and total solids. The hardness is mostly *permanent, *i.e.*, sulphate or non-carbonate, in character, and the nitrate content is usually high, but the organic purity may be satisfactory. These waters are corrosive and actively plumbo-solvent, and severe plumbism may arise from their use with lead pipes in domestic distribution systems. The factors which inhibit the formation of a protective carbonate film on the pipes are a deficiency of calcium bicarbonate, and the presence of free carbon dioxide, probably accentuated by the presence of high salinity and nitrates. The latter would not be active if the carbon dioxide-bicarbonate condition were satisfactory, but they probably play some part in the oxidation and reduction reactions which occur during the corrosion arising from the non-deposition of calcium carbonate.

The sources of waters of this character are usually shallow wells of small yield, so that the problem of their treatment for large public supplies does not arise. Treatment consists in aeration and the addition of a small dose of lime for the purposes of removing free carbonic acid and increasing the calcium bicarbonate content of the waters. Alternatively, and preferably, lead pipes should not be used.

Group 3. The waters included in this group are ferruginous in character and contain appreciable free carbon dioxide. Manganese may

also be present. Correct treatment consists in removing the free carbon dioxide and suitably raising the pH , in addition to the removal of iron and manganese (see Chapter XLIV). Several instances have, however, come to our notice in which, owing to ready flocculation of the iron, treatment consisted solely of rapid filtration, with or without prior settlement of the water. The water is thus rendered clear and bright, but, owing to the retention of the greater part of the free carbonic acid, it remains corrosive to metals. Such treatment is, therefore, ill-devised, and it should include removal of the free carbonic acid by aeration, and, if necessary, the addition also of lime prior to sedimentation and filtration.

Group 4. These waters are characterised by high contents of calcium bicarbonate and free carbon dioxide, and they are yielded typically by wells in the Chalk and Limestone. Since they possess adequate calcium bicarbonate for metal protection purposes, the only treatment required is the removal of free carbon dioxide. Aeration usually suffices to achieve this result, and, whenever possible, the omission of lime is preferable, since lime increases the hardness, and the waters are already hard. Softening of these waters by the lime process should always be considered, since this process not only removes the greater part of the hardness but also neutralises the carbonic acid and renders the waters non-corrosive. Failing lime-softening, and when circumstances do not permit efficient aeration, lime, sodium carbonate, or sodium hydroxide, can be used for the removal of free carbon dioxide. The latter two reagents have the advantages, compared with lime, that solutions are more easily prepared and administered, and no increase in hardness is caused.

Careful selection of chemicals is necessary according to the character of the water, since, if the free carbon dioxide is high and the calcium content of the water low or moderate, the use of sodium salts may result in a final water having characteristics somewhat similar to those included in Group 5.

Group 5. The waters of this group are characterised by high pH and the presence of a considerable amount of sodium bicarbonate. The total solids are usually high and include sodium sulphate and sodium chloride. Nitrates are low but free ammonia is often very high. Such waters are derived from the Thanet Sand and Chalk of the London Basin, and occasionally from other formations, such as the Lower Greensand. The calcium bicarbonate content of these waters is relatively low and free carbon dioxide is absent, or present in only minute trace. Although actively corrosive to iron, steel, galvanised iron and zinc-containing alloys, these waters are not plumbo-solvent. Elimination of all free carbon dioxide and raising the pH value does not correct the corrosive properties, and more complicated treatment is necessary. This usually consists of the addition of appropriate quantities of lime together with either calcium sulphate or calcium chloride, when calcium carbonate is precipitated and the sodium bicarbonate of the water is replaced by sodium sulphate or chloride. Sedimentation and filtration

of the chemically treated water are then required to remove the precipitated calcium carbonate. The resultant water has *pH* of approximately 9, and corrosion difficulties are restrained. Careful control of the treatment is necessary, and after-deposition of calcium carbonate in mains and pipes is a not infrequent complication. No reduction in the total solids of the water takes place, but the hardness may be slightly decreased.

Possible alternative methods of treatment, of which, however, there is at present little practical experience, consist of : (a) removal of sodium bicarbonate by synthetic resins, *i.e.*, partial demineralisation (see Chapter XLIII); and (b) the addition to the water of a small dose of lime, with or without a small dose of sodium hexametaphosphate.

After softening by the base-exchange process, waters possessing high calcium bicarbonate hardness become somewhat similar to the above, inasmuch as the calcium bicarbonate is converted into sodium bicarbonate, and corrosive action may then result, particularly if much free carbon dioxide is also present. Aeration for the removal of the free carbon dioxide usually suffices to restrain corrosion. If, however, it is desired to reduce the sodium bicarbonate content and the total solids of the water, a combination of zeolite softening and demineralisation by synthetic resins can be employed (see Chapter XLIII).

In a few instances, the waters concerned with corrosion cannot be placed in any of the above five groups and the cause of the trouble may be very difficult to discover and remove. It may possibly be explained by galvanic action arising from the union of dissimilar metals, such as copper and galvanised iron, or by the earthing of electrical currents. Faulty galvanising may also be responsible for localised corrosion in domestic cisterns, etc., and the presence of particles of iron or copper left on the surfaces of the galvanised iron tanks or pipes during installation may lead to corrosion and pitting.

The installation of chlorination, with or without ammonia, may also initiate corrosion in a system where previously it had not appeared. It is probable that in such cases the chlorine, chloramine, or other chlorination products, provide an additional oxidising factor which just suffices to overcome the previous capacity of the water to establish and maintain a protective film on the surfaces of the metal. Corrosion of brass fittings and of soldered copper ball-valves of flushing cisterns is common with chlorinated waters.

In addition to the above, corrosion and "rusty water" troubles are not infrequent in rural districts where the water is conveyed through unusually long lengths of distribution mains, from which, owing to the sparsity of population, there is comparatively little draw-off. Stagnation of water and long contact with the metal surfaces thus take place, particularly in "dead-end" mains, and there results brown discoloration of the water, with turbidity and ferruginous deposit, causing serious complaints. In addition, the development of an offensive odour of sulphuretted hydrogen in the water drawn from the consumers' taps may accentuate the complaints. In several of the

instances which we have investigated, the waters as pumped from the wells, or sampled from mains in the vicinity of the waterworks, showed none of the usual analytical results of corrosive waters, and they could not be included in any of the five groups of Table I. It was observed, however, that the sulphate content of these waters tended to be rather high in relation to the bicarbonate, and minute traces of sulphuretted hydrogen were occasionally present in the water delivered from the wells. It is suggested, therefore, that a lack of oxygen in the water, giving rise to an anaerobic condition in the mains, is a factor in the development of rusty water troubles, and this view receives support from the improvement which has been noted following the installation of aeration of the water before entering the mains. In such aeration, minute traces of carbon dioxide and sulphuretted hydrogen are, of course, removed from the water, in addition to the introduction of oxygen. Inspection of the mains in these instances usually reveals a tubercular type of incrustation, the tubercles being reddish-brown in colour on the surface but black beneath, and, on fracture, sometimes releasing black water or slime with a strong odour of sulphuretted hydrogen, thus indicating an anaerobic condition and the formation of sulphides. Under such conditions, in which biological activity probably plays a part, the water acquires iron in solution in a reduced or ferrous state. Hence, when drawn from taps, the water may initially be clear, but, after short exposure to the atmosphere, wherein the iron becomes oxidised and precipitated, there develops marked brown turbidity and deposit.

Unless suitable precautions are taken, corrosion and rusty water troubles in widely dispersed mains systems will become more frequent, in view of the anticipated development of piped water supplies to rural areas. In some instances, simple aeration may suffice; in others, the addition of small doses of lime and sodium hexametaphosphate may be required; whilst in others, consideration should be given to more comprehensive treatment, such as lime-softening when the waters are hard in character. The mere addition of a small dose of lime may remove free carbon dioxide and promote the development of a protective carbonate film on the surface of the mains in reasonable proximity to the waterworks. In more distant parts of the mains, however, this protection may not take place, and the use of sodium hexametaphosphate is designed to delay the carbonate deposition and thus carry the protection further afield. Careful adjustment of the dose of hexametaphosphate is required, but usually doses of the order of 0.25 to 1.0 part per million suffice.

When the only treatment required for the prevention of corrosion is the removal of free carbon dioxide, it is sometimes practicable and efficacious, in small supplies, to filter the water through a bed of magnesite. The latter is a granular material composed chiefly of magnesium oxide. It combines with carbon dioxide to produce magnesium carbonate which is dissolved by the water, and increases the temporary or carbonate hardness. A pressure filter can be used, and periodical replenishment of the magnesite is required.

Filters or contact beds of limestone chippings are sometimes used for the removal of acidity from water, and the prevention of corrosion and plumbo-solvency. They are seldom satisfactory owing to the rapid development on the surfaces of the material of a film which prevents further neutralising action.

Another anti-corrosion device of recent introduction is termed "Cathodic Protection," and is intended principally for the protection of storage tanks. The tank is made the cathode of an electrolytic cell, a small potential being placed from it to carbon electrodes immersed in the water. A minute concentration of hydrogen thus occurs at the surface of the metal and prevents oxidation.

External Corrosion of Water Mains. In certain localities, the external corrosion of water mains causes considerable difficulties. Clays containing calcium sulphate (gypsum), and soils containing peaty and other organic matter, are particularly troublesome. This external corrosion is somewhat analagous to that mentioned as taking place under anaerobic conditions, in which reduction of sulphates occurs, and biological factors are implicated. It is combated by applying thick bituminous or asphalt coatings and other wrappings to the mains, by embedding the mains in sand or chalk before filling the trenches in which they are laid, or by using bituminous coated asbestos-cement mains.

References

- BAYLIS. 1935. *Journ. of the Amer. Wat. Wks. Assoc.*, 27, 2.
BUNKER. 1944. "The Corrosion of Mains in Clay Soils." *Journ. Inst. San. Engrs.*, 5, Jan. 1944.
LANGELIER. 1936. *Journ. of the Amer. Wat. Wks. Assoc.*, 28, 10.
WATER POLLUTION RESEARCH. 1934. Department of Scientific and Industrial Research. Technical Paper No. 4. "The Action of Water on Lead with Special Reference to the Supply of Drinking Water." H.M. Stationery Office.

CHAPTER XLVI

FUNGAL AND ALGAL GROWTHS IN WATER PREVENTION AND REMOVAL

THE life which develops in waters exposed to the atmosphere and sunlight, such as in rivers and impounding reservoirs, consists of vegetable and animal forms, both of which include macroscopic and microscopic varieties. The plants include the large rooted vegetation of shallow waters, together with algæ, fungi and bacteria. Both algæ and fungi may individually be microscopical, but, by multiplication and aggregation, they produce readily visible growths. The animal life includes fish, crustacea, worms, insect larvæ and many microscopical organisms, such as protozoa.

All of these organisms are of importance in respect of the purity and purification of waters and many are illustrated in the Plates at the end of this volume, but, for detailed description, the reader is referred to "The Microscopy of Drinking water," by Whipple and Fair, and "Fresh Water Biology," by Ward and Whipple.

If kept under control, the large rooted vegetation which develops in the "shallows" of impounding reservoirs is beneficial rather than harmful, but, if the growths become unduly luxuriant, the organic matter added to the water, when the plants die and decompose, promotes the growth of other forms of life and also causes water purification difficulties.

The free-floating forms of life, *e.g.*, algæ, are known as plankton, and they include numerous varieties, some of which thrive at one season of the year and some at another. Although multiplication generally takes place during sunny, warm weather, certain unicellular motile organisms, such as Protococci and Euglena, may be troublesome in the winter months, particularly with the onset of severe frost. They may permeate slow sand filters, appear in the filtrates and impair the clarity and palatability of the water.

Algæ are chlorophyll-containing, unicellular or multicellular, organisms, dependent on sunlight for their existence. They are usually green or blue-green in colour but some forms contain brown, purple or red colouring matter.

The fungi do not contain chlorophyll and are not dependent on sunlight for their existence. They are usually grey in colour, or brown when iron is accumulated in the growths. Fungal growths may, therefore, flourish in the dark, such as at the bottom of reservoirs or in pipe-lines. Profuse growths of certain species, *e.g.*, *Leptothrix* and *Sphærotilus*, may, however, occur in positions exposed to sunlight, such as on the beds of shallow streams and on the surface of water contained

in tanks. Some forms grow best under aerobic conditions, whilst others either require, or prefer, anaerobic conditions.

In addition to the excremental and pathogenic bacteria which have been described in previous chapters, other species of bacteria, together with higher forms of life, such as algæ and protozoa, may, therefore, be present in waters used for public supply purposes, particularly in those derived from surface sources. In several instances we have known deep boreholes to become infected and profuse growths of fungus to develop underground, with the result that the water pumped from the boreholes habitually contained fungal threads.

The growth of both fungi and algæ is influenced by seasonal conditions and the mineral and organic constituents of the water, the latter being very important. Their undue prevalence, or sudden multiplication, in waters, may give rise to serious difficulties which include (a) clogging of filters, pipes, meters, etc., and (b) the production of turbidity, discoloration, odour and taste in the water. Special measures of treatment, either preventive or remedial are, therefore, required.

Higher Bacteria and Fungi. Of these organisms, the commonest which cause troubles in public water supplies are the "iron-bacteria," such as *Crenothrix*, *Leptothrix* and *Gallionella*, and, less frequently, *Sphærotilus*, *Leptomit* and *Beggiatoa* (see Chapter XI). *Anthophysa*, which is a member of the protozoa, forms brown growths and deposits suggestive of "iron-bacteria," and it is often found in stagnant, shallow waters, such as in swamps.

"Iron-Bacteria." The presence of iron or manganese in water encourages growths of "iron-bacteria," particularly when some organic matter is also present. Neither light nor oxygen is essential and growths are, in fact, often prominent in the dark in waters deficient in oxygen. Slimy, streamer, brown-coloured growths may form in tanks, on sand filter beds, in the underdrains of sand filters and in the distribution mains. Filters may, therefore, become blocked, requiring frequent cleansing, and pipes may become clogged. Growths of "iron-bacteria" are encouraged by acidity and inhibited by alkalinity. They are, therefore, often associated with corrosion and tubercular incrustation of mains.

The presence of these growths accentuates the brown discoloration, turbidity and deposit in ferruginous waters, and, when profuse growths die and decompose, they impart objectionable odour to the water. On account of the clogging effects on waterworks plant, and the interference with the appearance and palatability of the water, it is highly desirable that growths of "iron-bacteria" should be prevented.

Prevention. The best line of defence against growths of "iron-bacteria" is the proper purification of the water before distribution to the consumers. If free carbon dioxide, iron, manganese or organic matter are present, and oxygen deficient, appropriate treatment, as described in other chapters, should be applied.

Briefly, this should consist of:—

(a) Aeration to remove free carbon dioxide, introduce oxygen and precipitate iron and manganese.

(b) The addition of lime to remove carbon dioxide, to precipitate iron and manganese and to increase alkalinity and pH.

(c) Sedimentation in tanks, and filtration to remove the precipitated iron and manganese together with organic matter.

Waters which have been rendered slightly alkaline in reaction, and have been properly treated to remove iron, manganese, and organic matter, will not develop growths of "iron-bacteria" in reservoirs, tanks and mains of distribution systems.

The removal of an existing growth from tanks and mains can be effected mechanically by scraping and vigorous washing, followed by heavy chlorination. The affected tanks or mains, after flushing, should be filled with chlorinated water having a residual chlorine reaction of 1 part per million, allowed to stand for twenty-four hours and then flushed to waste. Particular attention should be paid to the flushing of "dead-end" mains.

In raw water tanks and pipe-lines, the development of growths can be restrained by regular chlorination in such a dose that the water flowing through the parts retains approximately 0.5 part per million of free chlorine.

Growths of "Fungus." Some of the higher bacteria, such as the "sulphur-bacteria," *e.g.*, *Beggiatoa*, develop in waters which contain sulphuretted hydrogen, even though the waters are of good organic purity. Efficient aeration and removal from the water of sulphuretted hydrogen will prevent fungal growths in such instances. More often, however, fungal growths are caused by organic contamination of the waters, although such contamination need not necessarily be marked. Often it appears to be the quality rather than the quantity of the organic matter which determines the onset of fungal growth. If the organic matter is well oxidised, fungal growths do not arise. The grey, slimy, growths often seen adhering to stones, vegetation, etc., in streams are due to fungi, of which *Sphærotilus* is a common member. These fungi are scavengers of organic matter and they thrive in streams to which inadequately purified sewage effluents and certain industrial wastes are discharged.

In cooling-water systems of factories in which crude river waters are circulated, and in pipe-lines conveying raw river waters to waterworks purification plant, slime growths of fungi frequently develop and cause blocking and other troubles. In such instances chlorination may be successfully employed as a preventive measure, sufficient chlorine being continuously added to the water to maintain a residual reaction of the order of 0.5 part per million. Alternatively, intermittent chlorination at a higher residual, *e.g.*, 5 parts per million, may suffice.

Growths of *Sphærotilus* and similar organisms may also appear in the underdrains of slow sand filters and in the filtered water tanks. Their presence in these positions is highly undesirable since they impair

the clarity of the water, cause objectionable odours and, by interfering with chlorination, jeopardise bacterial safety. The discharge to slow sand beds of water of high organic matter content, together with inefficient filtration by too high a rate of flow, conduces to these effects. The remedy consists, therefore, in reducing the organic matter content of the water by appropriate coagulant treatment, sedimentation and efficient rapid filtration, and, if the process is employed at all, by slow sand filtration at a reduced rate of flow.

Removal of fungal growths from filter beds can be effected by draining the beds and back-filling the underdrainage system with water containing 1 part per million of chlorine, allowing to stand for twenty-four hours and then flushing to waste. If the growth has become very profuse it may be necessary to repeat the treatment.

Protozoa. Undue multiplication of certain forms of protozoa, such as *Synura*, *Euglena*, *Cryptomonas* and *Chlamydomonas* may occur, particularly in the winter months, and give rise to filtration difficulties. These organisms may penetrate the sand beds and cause serious deterioration in the filtrates. If multiplication of such growths appears imminent, control should be exercised by copper sulphate treatment or prechlorination of the water.

Algæ. Whenever water is exposed to air and sunlight, algæ gain access in the same manner as weeds appear in a garden. If conditions are favourable, profuse growths of great variety develop and cause considerable troubles. The latter include the clogging of filter beds and the production of turbidity, discoloration, odour and taste in the water.

Since sunlight is essential to their growth, algæ are usually particularly prevalent in shallow waters and in the upper layers of deep waters. The chief factors which encourage algal growth in water are :—

- (a) Exposure of the water to sunlight.
- (b) Clarity of the water, owing to the deeper penetration of light.
- (c) Stagnation of the water.
- (d) The presence in the water of such mineral constituents as silica, phosphates and bicarbonates.
- (e) Moderately high pH value : reaction neutral to faintly alkaline.
- (f) Suitable temperature.

Algæ grow profusely in such clear and bright, moderately mineralised and organically pure waters as those derived from the Chalk. On the contrary, they are only sparsely present in the coloured, faintly acid and feebly mineralised waters of moorland and upland gathering grounds. Contrary to fungi, organic matter is not the principal food for algæ, but light, carbon dioxide and mineral matter are more important. There is, for example, a noticeable fall in the silica and phosphate contents of a water following an outbreak of algal growth. The presence in water of organic matter does, however, encourage the growth of certain forms of algæ and protozoa. Prevention of pollution does not, therefore, avoid algal growth in water and the purest of waters may become seriously affected if exposed to sunlight.

Temperature is not of great importance, and algal growth, although

usually more active in the summer months, probably as a result of more sunlight, continues during the winter. Seasonal prevalence is, however, a noticeable feature of algæ, and certain forms, such as diatoms, are often particularly prevalent in spring and autumn.

TABLE I
COPPER SULPHATE REQUIRED FOR ERADICATION
OF DIFFERENT ORGANISMS, AT 15° C.

(WHIPPLE AND FAIR)

Organisms.	Copper Sulphate, Parts per million.	Organisms.	Copper Sulphate, Parts per million.
CYANOPHYCEÆ :		DIATOMACEÆ :	
Anabæna . . .	0.12	Asterionella . . .	0.12-0.20
Aphanizomenon . . .	0.12-0.50	Fragilaria . . .	0.25
Clathrocystis . . .	0.12-0.25	Melosira . . .	0.33
Cœlosphaerium . . .	0.20-0.33	Navicula . . .	0.07
Microcystis . . .	0.20	Synedra . . .	0.50
Oscillatoria . . .	0.20-0.50	Stephanodiscus . . .	0.33
		Tabellaria . . .	0.12-0.50
CHLOROPHYCEÆ :		SCHIZOMYCETES :	
Ankistrodesmus . . .	1.00	Beggiatoa . . .	5.00
Chara . . .	0.10-0.50	Crenothrix . . .	0.33
Cladophora . . .	0.50	Sphærotilus	
Closterium . . .	0.17	dichotomus . . .	0.20
Cœlastrum . . .	0.05-0.33		
Desmidium . . .	2.00	FUNGI :	
Draparnaldia . . .	0.33	Leptomitius . . .	0.40
Eudorina . . .	10.00		
Enteromorpha . . .	0.50	PROTOZOA :	
Hydrodictyon . . .	0.10	Ceratium . . .	0.33
Microspora . . .	0.40	Chlamydomonas . . .	0.50
Palmella . . .	2.00	Cryptomonas . . .	0.50
Pandorina . . .	10.00	Dinobryon . . .	0.25
Scenedesmus . . .	1.00	Euglena . . .	0.50
Spirogyra . . .	0.12	Glenodinium . . .	0.50
Staurastrum . . .	1.50	Mallomonas . . .	0.50
Tribonema . . .	0.25	Peridinium . . .	0.50-2.00
Ulothrix . . .	0.20	Synura . . .	0.12-0.25
Volvox . . .	0.25	Uroglenopsis . . .	0.05-0.20
Zygnema . . .	0.50		

Prevention. The most important preventive measure is the exclusion of sunlight. It is manifestly impossible to apply this to many surface sources, such as rivers and large impounding reservoirs, but underground waters should never be exposed to sunlight. Collecting tanks for spring and well waters, and service reservoirs for pure and purified waters, should always be efficiently covered, when algal growth will not occur.

Some restriction of growth in large reservoirs is possible by avoiding shallow areas and maintaining circulation of water. Wave action on water in reservoirs, caused by wind, is beneficial in disintegrating algae and preventing multiplication.

Often, the algae are not unduly numerous or of objectionable variety, and purification by ordinary methods of filtration, etc. proceeds without difficulty, removes the organisms, and provides an entirely satisfactory final water. The algae may, however, be so numerous, or of such varieties, that the sand beds of the filters become clogged with excessive frequency or inefficient filtration occurs, with the production of a discoloured, turbid water having objectionable odour.

In order to avoid these effects, it is sometimes necessary or desirable to prevent excessive algal multiplication, or to destroy an existing growth, by the addition to the water of chemicals.

Algicidal Agents. The chief chemicals used for the control of algal growths are copper sulphate and chlorine. The presence in water of minute traces of certain metals, *e.g.*, copper, silver and zinc, inhibits algal growths.

Copper Sulphate. Copper sulphate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, is the most convenient form in which to add the metal. It is comparatively cheap, effective in great dilution and readily soluble in water, a saturated solution containing 38.7 per cent. W/W. The chemical can be added to the water by solution-feed in certain instances, such as when water is entering a reservoir or tank by a single feeder stream, pipe-line or channel, and a dose of 0.5 to 1.0 part per million is usually sufficient. The doses of copper sulphate required to kill many different organisms are given in Table I, but these doses are not always sufficient and effective in practice when dealing with established growths of mixed character. It is usually necessary to ascertain by trial the effective dose in each particular instance. Whenever possible, it is preferable to treat water with copper sulphate before algae have become prevalent, when smaller doses suffice. Higher doses are required to kill a well-established growth, and, in doing so, the decomposition of the organisms imparts much colouring organic matter and odour to the water. Also, the destruction of one form of growth may be followed by the excessive multiplication of another.

There is considerable difficulty in diffusing copper sulphate throughout the water contained in a large reservoir. Methods employed in such instances are usually crude, and require to be repeated at intervals according to the condition of the water, which is assessed by systematic sampling and determination of the algal content. One method consists of spraying calculated amounts of copper sulphate as uniformly as possible over the surface of the water by means of a small pump and spray conveyed in a boat. In another method, sacks of copper sulphate crystals, attached to the stern of a boat and immersed just below the surface of the water, are towed backwards and forwards across the reservoir until the whole surface has been treated.

Algal growths are often attached to the concrete sides of reservoirs

and open tanks, particularly when these are sloped so that there is a peripheral shallow area of water. In some cases in which the slopes are alternately submerged and exposed, it is practicable to spray or brush them intermittently with a mixture of copper sulphate and lime. This treatment is beneficial in preventing growth and attachment of algæ.

With any reasonable dosage, there is no danger to the consumers of copper poisoning. The treatment is usually applied to untreated waters, and the copper added is mostly deposited as insoluble carbonate and hydrate in the reservoirs or on the sand filters, so that infinitesimal traces, if any, appear in the final waters. Assuming the addition of a dose of copper sulphate of 0.8 part per million, and *all* remained in the water, the concentration of copper present would amount to approximately 0.2 part per million, which is innocuous. Fish may, however, be killed by copper sulphate treatment of water and care must, therefore,

TABLE II

CONCENTRATION OF COPPER SULPHATE THAT WILL KILL FISH
(WHIPPLE AND FAIR)

Fish	Copper Sulphate Parts per million
Trout	0.14
Carp	0.30
Suckers	0.30
Catfish	0.40
Pickrel	0.40
Goldfish	0.50
Perch	0.75
Sunfish	1.20
Black Bass	2.10

be taken if fishing is of importance. In waterworks reservoirs, fishing is a consideration which usually can well be ignored.

The concentrations of copper sulphate in water which are said to kill certain fish are shown in Table II. The death of fish in reservoirs, following copper sulphate treatment, may sometimes not be due to copper poisoning but to depletion of oxygen dissolved in the water by the oxygen demand of the decomposing algæ, or, alternatively, to clogging of the gills of the fish by the dead organisms.

Algæ are an important constituent of the biological growth which develops on the surface of slow sand filters, since they play a major part in the purification of water by filtration. The growth may, however, be unduly luxuriant, cause filtration difficulties and necessitate excessive frequency of cleansing. Control of algal growths in such positions is, therefore, often desirable, and chlorination provides a convenient method.

Chlorine. Chlorination of water can be successfully employed in some instances to restrain algal growth. Raw surface waters have, however, a high chlorine demand and the residual chlorine is quickly lost on exposure to air and sunlight. The use of ammonia and chlorine to form the more stable chloramines partly overcomes this difficulty.

In one instance of our experience, chlorine alone is added to the raw water about one hour before slow sand filtration and a residual chlorine reaction of approximately 0.2 part per million remains in the water on reaching the sand beds. This treatment exerts some restraining influence on biological activity on the surface of the sand, with the result that the "runs" of the filters before cleaning is required have been greatly extended, without impairment of the filtration results.

In other instances, it has been found practicable to treat waters entering open reservoirs, even of large size, with ammonia and chlorine so that small residual reactions of 0.2 to 0.5 part per million persist to the outlet, with considerable benefit in preventing undue algal multiplication.

A combination of chloramine and copper sulphate, the so-called cuprichloramine, was suggested by Harold (1934). In view of the selectivity noted in the use of these chemicals, copper sulphate being the more lethal to some organisms and chlorine to others, and the fact that the copper component does not precipitate and settle so quickly, cuprichloramine should prove more generally effective than either copper sulphate or chlorine alone. At present, however, there is little practical experience of its value.

Chlorination can sometimes be effectively employed for the removal of algal growth from tanks and channels. Water containing 0.5 to 1.0 part per million of chlorine should be allowed to remain in contact with the affected surfaces for several hours and then flushed down with clean water. Most algae are killed within an hour or two by water containing 0.5 part per million of chlorine, but the spores or seeds may be more resistant and require higher chlorine concentrations and repetition of the treatment.

Prevention of algal growths in swimming baths by the chlorination usually employed in such installations sometimes fails, particularly in open-air pools, and intermittent addition of copper sulphate to the water is then required. Chlorination is also employed for the treatment of crude water used in industrial cooling systems in order to prevent clogging of the pipe-lines by biological slime, which includes algae.

Activated carbon has occasionally been employed to combat algal growths in open reservoirs. Finely-divided powdered activated carbon is sprinkled evenly over the surface of the water on which it floats as a film. This, by obstructing sunlight penetration, and possibly by other means, prevents algal multiplication and also leads to the death and deposition of existing growth.

In public water supplies, the use of algicides should be avoided whenever possible, and the difficulties arising from algae prevented by other means. These means include the covering of reservoirs, when

feasible, and the efficient treatment of the waters by coagulants, sedimentation and filtration. Important points to observe in the construction of large reservoirs which it is impracticable to cover, are the removal of organic matter from the site, the avoidance of shallow areas as much as possible, the prevention of areas of stagnant water, and the arrangement of outlets so that water can be drawn off from different levels below the surface. Since algæ are more prevalent in the top layers, the abstraction of water at a depth of several feet below the surface may sometimes overcome serious filtration difficulties. The depth of the water of best condition varies from time to time, and, hence, the provision of controllable draw-off outlets at different depths has considerable advantage.

It is also emphasised that algicides, if used at all, should be administered to prevent undue multiplication of algæ rather than to destroy an existing luxuriant growth. The after-effects of algicides used for the latter purpose are sometimes very objectionable, the water becoming so organically impure, discoloured and malodorous as to be untreatable by ordinary methods. Filter beds may become completely clogged by the dead organisms, and efficient chlorination of the water prevented by the heavy chlorine absorption of the organic matter and the accentuation of the odour which it produces. Owing to the presence of increased food supply, *i.e.*, organic matter, and the elimination of antagonistic organisms, there is often considerable multiplication of bacteria in water following algicidal treatment.

Often, therefore, the attempted cure of algal troubles by the use of algicides brings no benefit, but, on the contrary, increases the difficulties. Careful consideration is, therefore, necessary before the procedure is undertaken and it should then only be carried out if skilled control is possible.

References

- HAROLD. 1934. 29th Annual Report to the Metropolitan Water Board, London.
- WARD AND WHIPPLE. 1918. "Fresh Water Biology." John Wiley & Sons.
- WHIPPLE AND FAIR. 1927. "The Microscopy of Drinking Water." John Wiley & Sons.

CHAPTER XLVII

COLOUR, ODOUR AND TASTE IN WATER PREVENTION AND REMOVAL

To the responsible authority, the production of a wholesome water supply is the primary consideration, and there is sometimes a tendency to ignore such matters as appearance and palatability. To the consumer, however, the latter qualities are important, and the presence of colour, cloudiness and odour in public water supplies gives rise to many complaints.

In certain areas, water supplies which are inferior in these qualities are accepted without widespread objections, either because the consumers have experienced nothing better, or because they have become convinced of the futility of complaint. With the greater knowledge and power of discrimination of the people, there is, however, a steadily increasing demand for betterment, and, in the near future, the present condition of some public water supplies will not be tolerated.

Since practicable methods to render water clear, colourless, bright and free from odour and taste are available in most instances, and such qualities will rightly be demanded in public supplies, water authorities should now give greater attention to these matters. Their duties do not end with the production of a water supply which contains no coliform bacteria in 100 ml., regardless of its appearance, palatability and hardness, and much more is required by the public.

Colour. A public water supply should have no noticeable colour, for such is the general requirement of consumers, and colour is the product of impurity of one kind or another. The commonest colours of water are yellow and brown, which are usually due to the presence of organic matter of vegetable or peaty origin. Such waters are frequent in the north of England, and supplies having colour as high as 200, Hazen Scale, are intermittently distributed to consumers. In the presence of this colouring organic matter, chlorination and treatment to prevent corrosion and plumbo-solvency, either or both of which are often required, become complicated and inefficient. Also, slow flocculation of organic matter takes place, producing deposits in mains and pipes which reduce their carrying capacity, and, on disturbance, cause turbidity as well as discoloration in the water drawn from consumers' taps.

The colouring organic matter should, therefore, be removed from the water and this can usually be effected by the use of coagulants, flocculating and settlement tanks, and rapid sand filters. Suitable treatment can then be efficiently applied for the correction of acidity and bacterial impurity, if required. As coagulants, powdered chalk

and aluminium sulphate are often the most satisfactory for the flocculation of organic colouring matter in acid, peaty waters. In some instances, the removal of colour will not be complete, and the required final result may then be obtained by the addition of powdered activated carbon to the partially clarified water discharged from the settlement tanks, prior to its filtration by rapid sand filters.

Ozonisation, as a terminal method of sterilisation of the filtered water, may sometimes be employed with advantage, since it may also remove the remaining traces of colour and odour.

Chlorination at very high dosage will considerably reduce the colour of waters, and this is claimed to be one of the merits of "break-point" chlorination (see Chapter XLI). There is, however, no experience to justify the substitution of coagulants, rapid sand filters and ordinary methods of sterilisation by "break-point" chlorination. The latter may, however, be applicable in certain instances, such as temporary emergencies, for the simultaneous removal of colour, odour, and bacteria from impure water.

Biological growths, such as algæ, impart various colours to waters, of which green and blue-green are the most common, but purple, brown and red may occasionally be produced. Such waters are decolorised by the removal of the growths by filtration, with or without the use of coagulants, according to the circumstances.

Colour in water is often "apparent" and not real, being due to the presence of suspended matter. Removal of the suspended matter by sedimentation and filtration also removes such "apparent" colour.

In a few instances, colloidal iron and manganese may be present in water and cause brown colour. Suitable treatment for the precipitation and removal of these metals will produce a bright and colourless water.

Green staining of water, baths, wash-basins, sponges, etc. sometimes occurs in domestic systems when water containing minute traces of copper, derived from pipes and cisterns, comes in contact with alkaline materials, such as soap and soda. The solvent action of water on copper is due to acidity. It is prevented by correcting the acidity by aeration for the removal of free carbon dioxide, or by the addition of alkali, such as lime.

The discharge of trade wastes to rivers may discolour the waters, or the disposal of dye-containing wastes in disused quarries, etc. may introduce colour to deep underground waters. Several instances of the latter have come to our notice, and, in one of these, the disposal of a material similar to trinitrotoluene in disused chalk quarries produced a canary-yellow colour which persisted for more than twenty years in a water supply obtained from a deep borehole sunk in the vicinity.

Activated carbon is often the best material for the removal of certain colours from waters which are free from suspended matter.

Taste and Odour. The senses of smell and taste are closely related, and complaints of objectionable tastes in water supplies are usually due to the presence of odour. Public water supplies should, however, be of such palatability that they produce no sensations of either taste

or odour. This condition may sometimes be very difficult to obtain in respect of every consumer, since there is a small minority of people who possess such delicate senses of smell and taste that they detect conditions which are non-apparent to the large majority. Also, waters differ in palatability according to their geological origin and characters, and a change in residence from one district to another may be responsible for spasmodic individual complaints of unpalatable water. For example, residents of a chalk water area would readily detect the different palatability of a peaty upland water, and *vice versa*.

Taste. Although the presence of odours always gives rise to complaints of taste, it is possible for waters to possess taste without odour. When this occurs, it is usually due to the presence of an excess of certain mineral or saline constituents. Sodium chloride (common salt) will, for example, impart its characteristic saline taste if present in more than small concentration. Waters having high contents of sodium sulphate may also be described as saline. Iron and manganese, if present in drinking water in more than minute traces, will produce an astringent, bitter or metallic taste. The presence of excess, or free, lime, or aluminium compounds, arising from errors in treatment, may have a similar taste effect.

Certain waters have an action on the palate which cannot strictly be described as taste. Chalk-derived waters, for example, possess a "sharpness" or pleasant palatability, probably due to the presence of carbon dioxide and calcium bicarbonate. On the other hand, waters derived from surface sources, and waters which are very soft, or are deficient in oxygen, are often described as "flat" or insipid. Long stagnation of water in mains and cisterns produces a similar condition.

The temperature of water also has some effect on palatability, and a cool water is usually more pleasant to drink than one which is warm, the latter being insipid. Heat may also accentuate odour, or cause odour, which was not observable in the cold water, to become evident.

Prevention and Removal of Taste. If taste is due to the presence of iron or manganese, there are usually other objections to the water, such as of turbidity and deposit. The obvious remedy is treatment at the source for the removal of iron and manganese from the water. If the iron is not initially present in the water, but is acquired from mains and pipes owing to corrosion or solvent action, appropriate treatment, such as aeration or addition of alkalies, should be applied.

Aeration often improves the palatability of waters which are described as flat or insipid. If the condition is caused by stagnation in mains, such as is common on "dead-end" mains, frequent flushing may be beneficial.

Saline taste, due to the presence of fairly high concentrations of sodium chloride or sulphate, has had to be tolerated, unless an alternative supply was available, since removal of sodium salts from water has hitherto been impracticable. The recent introduction to waterworks practice of hydrogen-ion exchange "zeolites" and synthetic resins (see Chapter XLIII) may, however, provide, in the near future, a practicable

method of treating saline waters for use as public supplies. Although a saline taste can be discerned in water containing about 50 parts per 100,000 of sodium chloride, waters containing more than twice that concentration are in habitual use in certain localised areas in Essex and elsewhere.

Treatment of water by activated carbon or ozonisation often improves the taste, but this is doubtless largely due to the removal of odour.

Odour. The presence of odour in water supplies is due to one or other, or a combination, of the following :—

1. The presence of sulphuretted hydrogen in the water.
2. Contact of the water with painted surfaces, such as the bituminous linings of mains and tanks.
3. Contamination by organic matter from sewage, manure, soil and vegetation.
4. Contamination by chemicals, such as from trade wastes.
5. Growths of algæ, protozoa, fungi, etc. in the water.
6. Treatment processes applied to the water, *e.g.*, chlorination.

Complaints of odour due to the presence of sulphuretted hydrogen are fairly common. Waters of good organic and bacterial purity, derived, for example, from deep underground sources, may contain traces of sulphuretted hydrogen. The latter may also be produced during passage of water through mains and pipes, owing to chemical or biological reduction of sulphates.

The remedy consists of the efficient aeration of the water before its discharge to the distribution mains. If sulphuretted hydrogen production is secondary to corrosion and a ferruginous condition of the water, appropriate treatment should, of course, be carried out to prevent the latter conditions.

Newly installed water mains and tanks, which are customarily protected by bituminous linings, may temporarily impart to water a tarry or aromatic odour, particularly if the linings are of inferior quality or are improperly applied. In a few instances, we have known troubles of this character to persist for many weeks. Careful selection of materials used in waterworks undertakings should, therefore, be made, and there are available bituminous preparations for pipe and tank linings which will impart no odour to water. Care is particularly necessary when dealing with chlorinated water, since infinitesimal traces of phenoloid substances given up by the linings to the water will produce iodoform or chlor-phenolic odours.

Undue organic contamination of water produces odours which are usually described as earthy, musty, weedy, or unpleasant. More offensive odours are, of course, caused by gross sewage pollution. Organic matter of vegetable origin often produces the "decaying vegetable" or "pond water-like" odours, and the odours of surface waters are often accentuated by, or due entirely to, algal growths. With the autumnal death and decay of plants in reservoirs, much organic silt is deposited on the bottom, where, if the depth is con-

siderable, anaerobic decomposition occurs. Should "turn-over" of water then take place, very organically impure, deoxygenated water, having marked colour and odour, may be brought to the surface and flow to the waterworks purification plant. Overloading of the latter may then occur and result in the production of an unsatisfactory final water in which distinct odour persists.

Pollution of sources of water supplies by trade wastes produces odours of various kinds according to the particular industries. Chemicals are employed in many industrial processes, and the presence of certain of these in small traces, together with other waste products, in the effluents, may impart odour to large volumes of water. With some contaminants, *e.g.*, phenoloid substances, the odours may become apparent in the water only after chlorination, which process of treatment is now in almost universal application.

Odours due to growths of algæ, protozoa, actinomycetes and other low forms of life are among the most frequent affecting water supplies derived from surface sources. These odours vary in character and intensity according to the type of growth and they may be musty, earthy, fishy, aromatic, etc. (see Chapter X). These odours also are often accentuated by chlorination of the water in ordinary doses.

The commonest form of water treatment which provokes odours is chlorination. Existing odours due to organic contamination or biological growths may be accentuated, or chlorinous, aromatic, "medicinal," iodoform and chlor-phenolic odours may be produced.

Prevention of Odours. Consideration of the causes of odours in water, which have been outlined above, will indicate some of the measures required for their prevention or restriction. These measures are :—

1. Prevention of pollution by sewage, trade wastes, etc.
2. Control of biological growths in reservoirs, sedimentation tanks and filters.
3. Careful attention to treatment processes, such as coagulation and filtration.
4. Strict control of chlorination and the use of ammonia or de-chlorinating agents.
5. Protection of water in distribution systems :
 - (a) Covering of service reservoirs.
 - (b) The installation of mains with linings of good quality ; avoidance of "dead-end" mains and of ball-hydrants ; regular periodical flushing of mains.

In spite of these precautions, instances occur, particularly in supplies derived from surface sources, in which the water retains a perceptible odour. Special treatment is then required for its removal.

Removal of Odours. The processes employed with varying success for the removal of odours from water consist of the following :—

1. Aeration.
2. The addition of chemicals, usually oxidising agents, such as ozone, potassium permanganate, hydrogen peroxide and chlorine.

3. The addition of powdered activated carbon, or filtration through beds of granular activated carbon.

Aeration. Aeration of water has many benefits which include the dissipation of free carbon dioxide, the introduction of oxygen, the precipitation of iron and the removal of certain odours due to volatile substances. Aeration effectively removes odour due to sulphuretted hydrogen but only partially removes, or leaves unaffected, odours caused by organic matter, biological growths or chlorination.

Efficient aeration takes place in fast-flowing streams, particularly when the water splashes over rocks, weirs, etc., and it plays an important part in the self-purification of rivers. From stagnant streams and impounding reservoirs, and occasionally from underground sources, poorly oxygenated water is obtained, and aeration is then a valuable part of the purification processes, and improves the palatability of the waters.

There are several methods of aeration of water. These include simple devices, such as cascading over weirs or waterfalls, splashing over shelves or aprons fitted around bell-mouth inlets to tanks, or spraying the water into the atmosphere in fine jets by a series of spray-nozzles arranged in tanks. In other instances, air is injected by pressure into a bulk of water contained in a tank, through a large number of nozzles, diffusion tubes, or plates, installed at the bottom of the tank. The object to be achieved in all cases is to bring air and water in contact as intimately and uniformly as possible. Aeration can also be obtained by forcing air upwards through an elongated chamber or tank containing material, such as pebbles, through which the water descends.

In industrial localities, the atmosphere, particularly in foggy weather, may contain sufficient traces of impurities to be detrimental for water aeration purposes. For example, the atmosphere may introduce minute traces of phenolic bodies which produce objectionable odours on chlorination of the water.

Potassium Permanganate. This chemical is occasionally employed to remove earthy and musty odours produced by organic matter and biological growths, but it can be added to water only in small traces and is seldom efficacious. Its addition to water in doses of 0.2 to 0.5 part per million prior to chlorination has sometimes been found to prevent some of the post-chlorination odours, but, for this purpose, it has now been supplanted by ammoniation and other methods.

Hydrogen Peroxide. Hydrogen peroxide has been used only on rare occasions in similar manner to potassium permanganate. Both of these chemicals have very limited application and have almost gone out of use since the introduction of activated carbon.

Ozone. Ozonisation is an effective method of sterilising water and has the additional advantages that it provokes no odour and will sometimes remove existing odour from the water. There is insufficient experience of ozonisation in this country to assess its general efficiency in the removal of odour from waters. In the few public water supplies in which it is used the results are favourable, but these are supplies

which do not present odour problems. In view of the frequent complaints of odour in chlorinated water, some of which might be avoided by improved application or more skilled control of chlorination, ozonisation will probably receive greater favour in the future as a process of water sterilisation and odour prevention. The installation of ozonisation for the sole purpose of odour removal would not be considered, since activated carbon treatment would be more suitable.

Chlorine. Super-chlorination or "break-point" chlorination (see Chapter XLI) may be employed for the removal of certain odours, such as those arising from organic matter and the products of biological growths. An excessive dose of chlorine, sufficient to break down and oxidise the odour-producing substances, is used. The colour and ammonia contents of the water are reduced, sterilisation is obtained, and the odour is either removed or becomes strictly chlorinous. The latter can then be destroyed by dechlorination.

Ammonia is used, in conjunction with chlorine, for the prevention of chlor-phenolic odours, but it is ineffective for their removal, or for the removal of odours due to products of algæ or decaying vegetation.

Chlorinous odours in public water supplies are usually due to the actual presence of free chlorine or chloramines, but occasionally complaints of chlorinous odour are made when no free chlorine reaction in the water can be obtained. Often, the chlorinous odour is observed only in domestic hot-water systems, particularly when a large volume of water is being drawn off, such as into baths, the cold supply being inodorous.

The removal of free chlorine from chlorinated supplies, after adequate contact time, is practised at many waterworks, and chlorinous odours are thus prevented. The dechlorination methods employed consist of the addition to the water of appropriate doses of sulphur dioxide or sodium thiosulphate, or filtration of the chlorinated water through a bed of granular activated carbon.

Activated Carbon. Charcoal has been used for many years for the removal of odour (and chlorine) from water, an example being the "De-Chlor" filter of the Candy Filter Company, units of which were installed at the Reading Corporation Waterworks in 1910. In recent years, improved forms of charcoal, known as activated carbon, have been manufactured, and these are now extensively used in waterworks treatment processes. In their manufacture from wood, lignite, peat, coal, etc., special precautions are observed to remove impurities and to obtain a maximum degree of porosity of the products. The final result is a comparatively pure carbon, in either powder or granular form, possessing a highly capillary structure, *i.e.*, an extensive surface area in relation to its volume. According to Braidich (1938), it has been estimated that a cubic inch of activated carbon possesses composite surface of more than 20,000 square yards. Activated carbons of various grades and properties are manufactured for use in different processes and they are extensively employed in industry. In waterworks practice, it is

necessary to specify the particular requirements, since a grade of carbon best suited for odour removal may not be equally efficient for dechlorination or removal of colour.

Removal of odour-producing substances from water by activated carbon is effected by the process of adsorption, in which efficiency is largely dependent on extensive surface areas. Activated carbon is, therefore, much more efficient than the ordinary forms of charcoal previously used in industry, and it can now be successfully and economically employed for the treatment of large public water supplies.

Activated carbon treatment is the most generally efficient method at present available for removing odour from water, and it has almost entirely replaced such expedients as the addition of potassium permanganate and hydrogen peroxide. It is used in either powdered or granular form, and the former is probably the more frequent. Powdered activated carbon is a fine, black, light powder, readily blown away by wind when handled in the open, and difficult to mix uniformly with water, a part floating on the surface. In its customary use for the removal of odour from water, powdered activated carbon is converted into a "slurry," *i.e.*, a suspension in water, which is kept as uniform as possible by mechanical mixers or air-blowers, and then fed into the water at constant rate. After allowing sufficient contact time, which preferably should be several hours if the necessary tanks are available, the carbon is removed on the sand beds of filters, which are usually rapid filters. From the latter the carbon is washed to waste in the back-washing process. No effort is made to recover powdered activated carbon and it is used, therefore, in the same manner as chemicals, such as chlorine.

In many instances, suitable contact tanks are not available and the carbon is then fed into the water as it flows to the rapid filters. This may yield satisfactory results, the accumulation of carbon on the surface of the sand beds having the desired effect. Economy in carbon consumption is achieved by the intimate admixture of water and carbon and by the provision of contact tanks.

The treatment is usually intermittent rather than continuous, since the presence of odours in surface waters, for which it is most often required, is occasional and seasonal. In some waters, however (see Chapter XLII), it will be found that the continuous addition of so small a dose of activated carbon as 1 part per million improves palatability, and thus the treatment can advantageously become routine.

Maximum efficiency of activated carbon treatment is obtained when the carbon is applied to clarified waters, *e.g.*, after coagulation and settlement, but it is occasionally added to raw waters. In the former, the doses usually vary from 2 to 10 parts per million, but in the latter, higher, and unduly extravagant, amounts may be required. The appropriate dose must be ascertained by experiment in each individual supply, and periodical adjustment made according to the condition of the water. Where double filtration is employed, such as rapid sand filtration followed by slow sand filtration, and no suitable tanks for

clarified water are available prior to rapid filtration, powdered activated carbon can be added, as a temporary expedient, to the primary filtered water. The carbon is then retained on the slow sand beds. At some waterworks, activated carbon is added with coagulants, such as aluminium sulphate, to the raw water, and it is then mostly deposited in the coagulating and settlement tanks. Benefit is thus sometimes obtained in removing odour, and the sludge deposited in the tanks is said to maintain a more satisfactory condition, putrefactive changes and odour production being restrained.

As a general rule, we recommend the addition of powdered activated carbon, when required, to waters which have been rendered clear and bright, rather than to turbid waters, since more satisfactory results are then obtained, together with considerable economy in carbon consumption. The presence in water of particles of suspended matter, iron, colouring organic matter, or alumina "floc," impairs the odour-removing capacity of carbon. Part of the adsorption activity of the carbon is expended in removing these impurities, for which ordinary and more economical methods, such as filtration, would suffice.

The presence of powdered activated carbon in water at the time aluminium sulphate is added improves flocculation, but a similar effect can often be obtained more economically by the use of finely-powdered chalk, such as that precipitated in the lime-softening of water.

Carbon is a dechlorinating agent, and hence, if sufficient chlorine contact time is not available at a prior stage of treatment, or it is desired to retain a residual chlorine reaction in the water, chlorination must follow removal of powdered activated carbon from the water. The addition of powdered activated carbon to water does not immediately dechlorinate, but chlorine is removed from the water by powdered carbon accumulated on the sand of filters. The use of powdered activated carbon for the control of algal growths in reservoirs has been mentioned in Chapter XLVI.

Granular activated carbon is used less frequently than the powdered form and in a different manner. It is not added to the water, but the latter is passed through rapid filters containing beds of granular activated carbon resting on pebble and sand layers. Such carbon filters are now more often employed for dechlorination of water than for odour removal, owing to the greater efficiency and economy of the powdered form for the latter purpose. In course of time, granular carbon filters lose adsorption capacity and the material has then to be replaced, or reactivated, and no satisfactory method of reactivation *in situ* has yet become available.

For the removal of free chlorine from water, granular carbon filters have a reasonably long life, provided the water is clear and bright in appearance and free from iron. The filters are usually pressure units, and, requiring little attention when in use, they are convenient for small supplies treated by superchlorination and dechlorination. If it is desired to retain a residual chlorine reaction in the final water, arrangements can be made to by-pass a fraction of the chlorinated water and

blend it with the remaining fraction of dechlorinated water in any predetermined proportion.

The carbon units should not stand idle for long periods, otherwise biological growths develop on the material and high bacterial counts appear in the filtrates. The maintenance of a fairly high chlorine content in the water fed to the filters prevents such growths and increases the active life of the carbon, but occasional back-washing with chlorinated water is often advisable in order to keep the lower layers of the beds and the underdrainage system clean and free from growths.

Rapid, activated carbon filters of the open, gravity type are occasionally used and we are aware of one installation which has been in successful operation for more than twenty years. This was installed to prevent chlorinous odours, and is, therefore, primarily a dechlorinating plant. The filters remove approximately 0.75 part per million of free chlorine from an organically pure Chalk-derived water, and they habitually yield a clear, bright, colourless and odourless water, containing no free chlorine. The installation comprises four units, and once a year the carbon is separately removed from each, spread out on a concrete surface and exposed to air and sunlight for three to four weeks, and then replaced in the filter. The capacity of the plant is thus maintained with very little addition of new carbon for make-up purposes.

Using granular activated carbon of suitable quality, the rate of filtration employed in carbon filters can be equal to that of rapid sand filtration. The size of the units and the depth of the beds are, therefore, somewhat similar to those of ordinary rapid sand filters. The flow of water is usually downwards, and occasional washing in the opposite direction is required.

The choice between dechlorination by chemical methods, such as by sulphur dioxide, and granular activated carbon filters, depends on the circumstances of the waterworks and the requirements.

When palatability is of prime importance, such as in the preparation of bottled mineral waters, carbon filters are preferable. They are convenient also in some small, semi-automatically operated waterworks to which a minimum of attention can be given. At large waterworks, dechlorination by chemical methods is usually employed.

As previously indicated, powdered activated carbon is found more suitable for odour removing purposes than granular carbon filters, and it is anticipated that it will find increasing use in waterworks practice. With the depletion of underground sources and the greater utilisation of rivers as sources of public water supplies, odour and taste problems will assume more importance in this country, particularly as the requirements of the consumers become more fastidious.

In activated carbon treatment there is now available a method by which the earthy, musty, weedy odours and insipid palatability of many supplies derived from rivers and impounding reservoirs can be prevented. Its application should, therefore, be considered for the improve-

ment of the palatability of some existing supplies, and provision made for its use in any new works designed for the treatment of surface waters.

References

BAYLIS. 1935. "Elimination of Taste and Odor in Water." McGraw-Hill Book Company.

BRAIDICH. 1938. *Jour. Amer. Wat. Wks. Assoc.* 30, 8.

CHAPTER XLVIII

PURIFICATION OF WATER FOR SWIMMING BATH PURPOSES

Suitability of Water for Bathing Pools

At one time, few facilities were provided for swimming and bathing except under natural conditions, but within recent years there has been a rapidly increasing provision throughout the country of artificial bathing pools, and the question of the purity of the water, being of importance to the Public Health, has received considerable attention. The establishment and control of public bathing pools are regarded as the duty of Sanitary Authorities, who are, therefore, responsible for the suitability, purity and safety of the water.

In the past these considerations were often ignored, and there is little doubt that inadequate facilities were provided and the bathing in impure water that resulted was responsible for many cases of disease. The desirability of the provision of ample facilities for swimming and bathing is evident, but certain dangers are incurred unless a high standard of purity is maintained in the water.

Bathing pools can be divided into :—

1. Natural.
2. Partly natural and partly artificial.
3. Artificial.

Natural bathing pools are usually found on rivers, ponds, etc., and in some cases the water is of satisfactory purity, the quality being maintained by an adequate flow of fresh water. Usually, however, the question of purity is ignored in these cases, although the water may be, and, in fact, often is, polluted and unsafe for bathing purposes. Where such conditions prevail, the responsible authority should warn the public of the dangers by posting notices on the banks of the river.

Some outdoor bathing pools at the seaside are designed so as to be emptied and refilled at each tide. Attention should be paid to the location of the bath, the direction of sea currents, and the quality of the water, for not infrequently foreshore sea-water, especially in estuaries and the vicinity of sewage outfalls, is seriously polluted by sewage. In many of such establishments the bacterial purity of the water is unsatisfactory and treatment plant is usually required.

Partly artificial pools on or near rivers and streams often depend solely on the natural flow of the water for purification, whilst in other cases, some system of filtration, usually coarse in character, is installed as an accessory measure of treatment.

Our investigations of many rivers in this country (see Chapter

TABLE I

TABLE OF ANALYSES SHOWING QUALITY OF WATER USED FOR THE FILLING OF NINE PUBLIC SWIMMING PLACES WHERE
NO PROCESS OF PURIFICATION WAS IN OPERATION

Results in Parts per 100,000

Source of water	Well.	Well.	Well.	River. Rough filtered.	River.	Serpentine, Hyde Park.	Sea. Tidal estuary.	Sea.	Sea.
Turbidity	Clear and bright.	Clear and bright.	Bright, few particles of debris.	Particles of debris.	Opalescent with deposit of debris and life.	Opalescent with deposit of debris, algae and other life.	Slight deposit of debris.	Slight opalescence and deposit of debris and other life.	
Colour A.P.H.A.	Normal.	Normal.	Normal.	Yellow 17.	Yellow 25.	Faint green.	Yellow 16.	Ft. yellow- green.	Ft. yellow- green.
Odour	Nil.	Nil.	Nil.	Earthy.	Earthy.	Earthy.	—	"Sea-weedy."	"Sea-weedy."
Chlorine in chlorides.	4.6	6.8	3.2	3.1	3.9	—	1840	1880	1885
Free ammonia	0.0024	0.0032	0.002	0.012	0.018	—	0.036	0.009	0.006
Albuminoid ammonia	0.0016	0.0024	0.0016	0.014	0.048	—	0.030	0.029	0.021
Oxygen absorbed in 3 hrs. at 37° C.	0.020	0.030	0.025	0.208	0.420	—	0.280	1.22	0.42
Bacterial count on— Gelatin 1 c.c. 3 days at 20° C. Agar, 1 c.c. 1 day at 37° C.	120 5	355 28	16,000 1,500	8,300 1,440	62,000 3,600	36,800 4,200	7,800 2,900	1,300 330	3,100 110
Bact. coli	—100 c.c.	—100 c.c.	—100 c.c.	+10 c.c.	+0.1 c.c.	+1.0 c.c.	+10 c.c.	+0.01 c.c.	+0.1 c.c.
Cl. welchii	—100 c.c.	—100 c.c.	—100 c.c.	+10 c.c.	+10 c.c.	+100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.

XXXV) indicate that the water is seldom of the standard of purity desirable for public swimming pool purposes, and also, that it requires more than rough filtration or straining to render it satisfactory. Efficient filtration and sterilisation are frequently required, and chlorination of streams is often practicable. In several pools of this type we have found the water, even when filtered, not of the standard that should obtain

TABLE II

SHOWING A RIVER WATER USED FOR SWIMMING POOL PURPOSES, AND THE SAME AFTER ROUGH FILTRATION, AND ALSO AFTER ONE WEEK'S USE IN THE BATH. SLIGHT CONSTANT FLOW THROUGH BATH, BUT NO OTHER TREATMENT.

Parts per 100,000.	Raw river water. Intake to bath.	Water after rough filtration entering bath.	Water at Outlet of Bath. Bath in use 1 week. 1,000 bathers.
Appearance . . .	Slight opalescence and deposit.	Very slight opalescence and deposit.	Sl. opalescence and deposit of debris and algæ.
Colour, A.P.H.A. . .	Sl. Yellow 24	Sl. Yellow 17	Yellow 55
Odour . . .	Earthy	Earthy	Earthy
Free Ammonia . . .	0.0198	0.012	0.028
Albuminoid Ammonia . .	0.031	0.014	0.086
Oxygen Absorbed . . .	0.267	0.208	0.880
No. of bacteria on Gelatin in 3 days at 20° C. per 1 c.c.	300,000	8,300	80,000
No. of bacteria on Agar in 1 day at 37° C. per 1 c.c.	26,000	1,440	5,400
Bact. coli	+ 0.1 c.c. - 0.01 c.c.	+ 10 c.c. - 1 c.c.	+ 1 c.c. - 0.1 c.c.
Cl. welchii	+ 10 c.c. - 1 c.c.	+ 10 c.c. - 1 c.c.	+ 10 c.c. - 1 c.c.

in an establishment for which the Sanitary Authority is responsible, and accordingly we have recommended chlorination.

In the construction of any new outdoor pool, careful consideration should be given to: (1) the selection of the site (there are few uncontaminated rivers, and a swimming pool should be situated above, or as far as possible below, a sewage works outfall); (2) the purity of the water throughout the bathing season; (3) the circulation of water through the pool; and (4) the system of treatment that may be required to maintain a satisfactory standard of purity.

Tentatively we suggest that a river water is unsuitable for use in a public bathing pool if it contains Bact. coli in 10 c.c. or less of water. Also, accessory treatment is required if the flow through the pool is inadequate to maintain the water free from Bact. coli in 10 c.c. during the time of maximum bathing load. Whatever the bacterial purity of the water, filtration is required if it is not clear and bright in appearance.

The same standards should apply to bathing pools at the seaside

operated on the "fill and empty" system at each tide. The "fill and empty" system was at one time common in indoor pools, but it has now been replaced by the continuous circulation and purification system in most of the larger public installations.

There are undoubted risks of contracting diseases in swimming pools which are inadequately equipped and supervised and employ no efficient method of treatment of the water. These risks are, however, reduced to a minimum in modern, well-organised pools where continuous circulation and purification of the water are efficiently operated. Swimming in unsatisfactory pools has been held responsible for cases of many different diseases including infections of:—

1. The ear; *e.g.*, otitis media.
2. The throat; *e.g.*, tonsillitis, etc.
3. The eyes; *e.g.*, conjunctivitis.
4. The skin; *e.g.*, ringworm, scabies, usually transmitted by costumes, towels, floors, etc.
5. The gastro-intestinal tract; *e.g.*, enteric fever, dysentery, etc.
6. The respiratory system; *e.g.*, bronchitis, pneumonia, etc.

Leptospiroid jaundice (Weil's disease) may be contracted in swimming baths, and cases of this disease have been recorded after immersion in river waters. There is also a possibility, though as yet no definite evidence, that virus diseases, such as polyomyelitis, may be contracted from water. The precise risks of communal bathing are difficult to assess, but, although they cannot be ignored, there have undoubtedly been many instances of ill-founded allegation.

Infections may be derived from polluted water entering the pool and also from matter subsequently added to the water from the skin, secretions and excretions of the bathers.

A problem which faces swimming pool managers is therefore that of providing a pure water and keeping it pure whilst in use. The artificial pool is usually filled with pure water either from the public water mains or from other suitable sources, such as wells. In order to keep it of suitable quality, such dilution is required by continuous flow that the costs of water and heating become prohibitive. The alternative devices that have been employed in baths include:—

1. The emptying, cleansing and refilling of the bath with clean water at intervals, say after one, two, three or more days, or even weeks, *i.e.*, the "fill and empty" system.

This is an unsatisfactory method, since the water, although good at the commencement, becomes, after a brief period of use, cloudy, polluted, and therefore dangerous to the bathers, both on account of its opacity and because no protection from infection of one bather by another is afforded. The periodicity of changing the water is often left to the discretion of the bath attendant, and is usually determined by the number of bathers who have used the pool, or the clarity of the water, both of which are uncertain criteria of bacterial impurity. We have known instances where the amount of algal growth was the determining factor in deciding on a change of water in the bath.

The "fill and empty" system is costly, unsatisfactory, and is not recommended.

2. The above method augmented by the periodical addition to the bath water of a disinfectant.

The disinfectant usually added is a chlorine compound, such as

TABLE III

SHOWING ANALYSES OF SWIMMING BATH WATER AT A PUBLIC BATH WITH NO SYSTEM OF PURIFICATION. WATER CHANGED AFTER TWO DAYS' USE. (SAMPLED ON THREE DIFFERENT OCCASIONS.)

Capacity of Bath . . .	100,000 gallons			Public Supply Water Used
Days in use . . .	One	One	Two	Metropolitan Water Board Average Analysis
Number of Bathers . . .	566	639	989	
Turbidity . . .	Slight opalescence and deposit of <i>debris</i> and low forms of life			Clear and bright
Reaction, pH . . .	7.8	7.8	7.8	7.8
Chlorine in Chlorides .	2.4	1.9	2.4	1.8
Free Ammonia . . .	0.048	0.024	0.075	0.0098
Albuminoid Ammonia .	0.015	0.012	0.017	0.008
Oxygen absorbed in 3 hours at 37° C.	0.105	0.163	0.165	0.09
Bacterial Count on Gelatin 1 c.c., 3 days at 20° C. .	210,000	400,000	480,000	Under 100
Bacterial Count on Agar 1 c.c., 1 day at 37° C. .	78,000	42,000	32,000	4
Bact. coli	+ 5 c.c.	+ 1 c.c.	+ 1 c.c.	— 100 c.c.
Cl. welchii	+100 c.c.	+100 c.c.	+100 c.c.	— 100 c.c.
Streptococci	+20 c.c.	+50 c.c.	+20 c.c.	— 100 c.c.

"Chloros" or "Voxsan." A quantity is added when the bath is filled, and further doses are given at intervals, such as nightly, when bathing has finished. This measure has some benefit, and reduces costs, since the water is changed less frequently. It is, however, a haphazard method providing doubtful and unreliable protection, and is not recommended. The turbidity and suspended matter contained by the water are not reduced, and may, in fact, be increased by this process. Free chlorine is rarely found in the water during bathing hours, and the dose of disinfectant periodically administered is usually too small and not uniformly dispersed throughout the water.

Our observations on establishments of the above character have shown that the baths are not clean, and usually collect slime on the bottom and sides, which, being slippery, is dangerous to bathers. The bacterial purity of the waters is variable and seldom satisfactory. Additional danger arises from the opacity or turbidity of the water since a bather falling to the bottom may not be seen soon enough to be saved.

Table III shows the results obtained at a bath worked on the "fill and empty" system, with no other treatment. The bath was filled with pure water from the public mains, and was emptied and refilled after two or three days' use, depending on the number of bathers. The samples were collected at the end of a day's run at a depth of 3 feet below the surface of the water at the deep end of the bath.

The results obtained in several baths where the "fill and empty" system was employed, augmented by the periodical addition of chlorine, are summarised in Table IV. The water used to fill the baths Nos. 2 and 3 was the same, and was derived from a borehole on the site. Owing to the unsatisfactory bacterial results, the system was discarded, arrangements made to keep the water in circulation during bathing hours, and to chlorinate it continuously by a gas-chlorine plant with such a dose that a residuum of about 0.2 part per million of chlorine was maintained in the bath. The bath was emptied and refilled every third day as before, and straining with no filtration was employed. Considerable improvement, as shown in column 4, resulted from this measure.

It proved, however, disadvantageous compared with the continuous purification and circulation method which will now be outlined, and in which the same water, with small daily additions of clean "make-up" water, can be used for months.

3. The continuous circulation and purification system.

In this system, the bath is filled with pure water, and, during bathing hours, the water is continuously circulated by pumps, passing from the bath, through the purification plant and thence back to the bath. The system is usually arranged so that water enters the bath at the shallow end and leaves at the deep end. The quality of the water in the pool depends on the capacity and efficiency of the purification plant and the number of bathers.

The bath is constructed for the accommodation of a certain number of bathers at any one time, and the circulation apparatus should be arranged so that a complete turnover of the water can be effected in three hours. The purification plant should be effective at this speed of operation, though a turnover in four hours is the more common rate under average conditions.

The water leaving the bath first passes through a strainer which removes much coarse matter, such as buttons, hairs, fibres, etc. A coagulant, usually aluminium sulphate, is then added in a dose of 1 to 2 grains per gallon, and an alkali, such as soda ash, is required, but is added only intermittently as a rule. It is desirable to maintain the

TABLE IV

SHOWING ANALYSES OF WATER IN PUBLIC SWIMMING POOLS WHERE THE "FILL AND EMPTY" SYSTEM IS EMPLOYED
WITH THE PERIODICAL ADDITION OF DISINFECTANT
Results in Parts per 100,000

Number		1.			2.			3.			4.			
Capacity of bath.		65,000 gallons.			98,000 gallons.			75,000 gallons.			The same as No. 3 but water circulated and chlorine gas added to maintain residual about 0.2 p.p.m. in bath. Water changed after 2 days' use.			
Disinfectant used.		Chloros.			Voxsan.			Voxsan.						
Amount and frequency.		1 quart when filled. 1 quart each day.			1 gallon when filled. Half gallon each day.			Three-quarter gallon when filled. Half gallon each day.						
Days bath in use.	Water used to fill bath.	2	3	Water used to fill bath.	1	2	4	Water used to fill bath.	1	2	2	1	1	2
No. of bathers.		448	1,130		271	764	989		493	1,346	1,613	550	762	
Chlorine in chlorides.	6.8	7.0	7.3	3.0	3.0	3.3	3.4	3.0	3.2	3.1	3.4	3.1	3.0	
Free ammonia.	0.0032	0.004	0.073	0.0024	0.057	0.068	0.050	0.0024	0.053	0.048	0.026	0.025	0.057	
Albuminoid ammonia.	0.0024	0.012	0.021	0.001	0.007	0.008	0.010	0.0018	0.012	0.010	0.005	0.009	0.014	
Oxygen absorbed 3 hrs. at 37° C.	0.030	0.040	0.065	0.028	0.035	0.040	0.055	0.028	0.055	0.035	0.125	0.070	0.065	
Bacterial count on gelatin, 1 c.c., 3 days at 20° C.	335	200,000	380,000	143	170,000	1,400,000	400,000	143	47,000	2,500,000	900,000	31	7	2,800
Bacterial count on agar, 1 c.c., 1 day at 37° C.	28	12,000	70,000	11	28,000	90,000	21,000	11	1,800	204,000	150,000	9	0	160
<i>Bact. coli</i> .	—100 c.c.	+50 c.c.	+1.0 c.c.	—100 c.c.	+10 c.c.	+20 c.c.	+10 c.c.	—100 c.c.	—100 c.c.	+5 c.c.	+1 c.c.	—100 c.c.	—100 c.c.	—100 c.c.
<i>Cl. welchii</i> .	—100 c.c.	—100 c.c.	+100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	+100 c.c.	—100 c.c.	+100 c.c.	—100 c.c.	+100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.
<i>Streptococci</i> .	—100 c.c.	—100 c.c.	+20 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	+100 c.c.	—100 c.c.	+100 c.c.	+100 c.c.	+20 c.c.	—100 c.c.	—100 c.c.	—100 c.c.

N.B.—Samples collected at end of day at deep end of bath.

reaction of the water at pH 7.5 to 8.0, and the alkali is added when the pH falls below this value.

The water then passes through rapid pressure sand filters, and a rate of 100 to 150 gallons per square foot per hour is usually suitable in plants of this kind. More rapid rates are used, but are liable to yield inferior filtrates. Sufficient filtering area should be provided to allow for units being stood off for washing, and to permit effective filtration at the maximum speed of turnover of the bath water.

Chlorination usually follows filtration, and is most conveniently carried out by gas chlorine plants whereby dosage can be accurately controlled and measured. Periodical adjustment of the dose is necessary according to the number of bathers and the residual chlorine reaction of the water in the bath. The dose should be so arranged that the residual chlorine content of the water in the bath does not fall below 0.2 parts per million, nor exceed 0.5 parts per million. Under such conditions the bacterial condition of the water is usually satisfactory and the chlorine is not unduly objectionable to bathers. In the first week or two of the bathing season, there may be, however, some difficulty in maintaining the residual chlorine in the bath water owing to the absence of ammonia. At the opening of the bathing season, the addition of ammonia to the water in a dose of approximately 0.1 parts per million is, therefore, often advisable. This ammonia reacts with the chlorine to form chloramines, and the latter, being more stable, persist longer in the pool. Also, chloramines give rise to less complaint from the bathers of chlorinous odour, and, so long as the chlorine to ammonia ratio does not fall below 2:1, the bactericidal action is satisfactory. In the re-circulation and re-use of the water there is, however, a progressive increase in its ammonia content owing to pollution by bathers. It becomes necessary, therefore, to suspend ammoniation in treatment, otherwise chlorination becomes inefficient. The use of the ammoniating plant can usually be discontinued for the remainder of the season when the analyses of the water passing from the purification plant to the bath habitually show a free ammonia figure exceeding 0.1 parts per million. In the course of time, and more quickly when large numbers of bathers use the pool, the ammonia content of the water becomes so high that it is necessary to increase the chlorine dose considerably in order to obtain satisfactory bacteriological results. Chlorination should be so arranged that the resulting ratio of chlorine to ammonia should be not less than 2:1. When this ratio becomes 1:1, sterilisation of the water is much retarded, and at such inverse ratios as 1:2 or 1:4, which may be found in practice, chlorination is ineffective and a satisfactory bacterial condition of the water in the bath cannot be maintained. Towards the end of the bathing season, it is not uncommon, therefore, to find a free ammonia figure of 1.0 to 3.0 parts per million, together with the presence of nitrites, and it is then necessary to add 2 to 5 parts per million of chlorine. It is often preferable, however, to run part of the bath water to waste and make up with fresh water. When the ammoniacal content of a bath water is high, residual chlorine

reactions of as much as 2 parts per million may be present without causing complaints by the bathers. The presence of coliform bacteria, recorded in bath waters showing distinct chlorine reactions when tested with ortho-tolidine solution, is usually explained by an inverse chlorine to ammonia ratio, or by a spurious ortho-tolidine reaction caused by the presence of nitrites. The use of the reagent known as "Chlorotex" (British Drug Houses) serves to distinguish between chlorine and nitrites.

In addition to filtration and chlorination, two further stages of treatment, *i.e.*, aeration and warming, are employed before the water re-enters the bath. The former is effected by the injection of air and/or cascading and is decidedly beneficial. A comfortable temperature of the water for the bathers is 22° C. The raising of the temperature also assists purification by accelerating the bactericidal action of chlorine.

The main objects of this system of treatment are :—

1. To remove suspended and colloidal matter and render the water clear, bright, colourless and odourless.
2. To remove organic matter.
3. To remove or destroy bacteria, and to render the water itself bactericidal.
4. To maintain slight alkalinity in the water (*pH* 8.0).
5. To maintain a comfortable temperature of the water.

The clarity of the water should be such that the bottom of the bath is clearly visible. This necessitates not only the continuous purification of the water, but also the periodical cleansing of the walls and bottom of the bath, and this is usually effected by suction apparatus and brushes.

Although the presence of odour in the water cannot be entirely avoided at all times, it should be barely perceptible and unobjectionable to bathers, and the water must also be non-irritating to skin, eyes and mucous membranes. Irritation is avoided by keeping the water free from excess of acidity, alkalinity and chlorine.

The bacterial condition of the water should approximate to that of drinking water. Experience indicates that with good installations, properly supervised and controlled, it is practicable to obtain a water of the following character :—

1. To contain less than 100 bacteria per 1 c.c. capable of growing on agar in two days at 37° C.
2. To be free from *Bact. coli* in 100 c.c. of water.
3. To be free from streptococci in 100 c.c. of water.
4. To give a negative "stormy-fermentation" (*Cl. welchii*) reaction in 100 c.c.

We suggest, therefore, that a standard set for indoor bathing pools operated on the continuous circulation and purification system can reasonably include :—

1. Absence of *Bact. coli* from 100 c.c. in 75 per cent. of samples, and absence from 10 c.c. in all samples.
2. Bacterial count on agar in two days at 37° C. to be less than

100 per c.c. in 75 per cent. of the samples, and not to exceed 500 in any sample.

We have not been impressed with the value of faecal streptococci, nor the bacterial count on gelatin at 20° C., as indices of pollution of

TABLE

SHOWING ANALYSES OF SAMPLES OF BATH WATER TAKEN FROM SWIMMING
SYSTEM (STRAINER—COAGULANT—RAPID
Results in Parts

Number . . .	M.W.B Water Used	Bath 1					
Time Bath in use in Months . . .	In Baths	1	2	3	4	5	1
No. of Bathers . .	Average Analyses	29,615	44,147	59,990	72,100	80,234	40,572
Turbidity . . .	Bright	Bright	Bright	Bright	Bright	Bright	Bright
Colour . . .	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Odour . . .	Nil	Faint Earthy	Faint Earthy	Faint Earthy	Faint Earthy	Faint Earthy	Faint Earthy
Reaction, pH . . .	7.8	7.8	8.0	8.0	8.0	8.3	8.3
Chlorine in Chlorides .	1.8	11.8	—	15.5	—	17.5	13.2
Nitrogen in Nitrates .	0.22	1.2	—	1.3	—	1.3	1.3
Free Ammonia . . .	0.0093	0.0072	—	0.0144	—	0.0072	0.019
Albuminoid Ammonia .	0.008	0.016	—	0.0216	—	0.016	0.019
Oxygen Absorbed in 3 hrs. at 37° C. . .	0.09	0.080	—	0.085	—	0.110	0.095
Bacterial Count on Gela- tin, 1 c.c., 3 days, at 20° C.	—	230	45	360	86	550	2,600
Bacterial Count on Agar, 1 c.c., 1 day at 37° C.	4	13	2	6	13	38	23
Bact. coli . . .	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.
Cl. Welchii . . .	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.
Streptococci . . .	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.	—100 c.c.

N.B.—Samples collected at deep

bath water, and think they can be omitted without sensible loss. The agar counts at 37° C. and the Bact. coli tests appear to us of greater merit.

The samples should be taken beneath the surface of the water (we suggest 3 feet) at the deep or outlet end of the bath. Samples should also be collected occasionally at the inlet to the bath to verify the efficiency of the treatment plant. Analyses should be regularly made throughout the bathing season.

It must be remembered that the bactericidal action of the free chlorine present in the water will continue during transit of the sample

to the laboratory. Therefore, on collection of the samples, the free chlorine should be destroyed by using bottles to which a trace of sodium thiosulphate has been added prior to sterilisation. A small crystal of "hypo" or 1 c.c. of a 1 per cent. solution of sodium thiosulphate

V

POOLS OPERATED ON THE CONTINUOUS CIRCULATION AND PURIFICATION FILTRATION—CHLORINATION—AERATION)

per 100,000

Bath 2				Bath 3	Bath 4	Bath 5	Bath 6		
2	3	4	5	5	4	4	2	2	2
60,957	83,775	—	104,000	112,000	Over 20,000	Over 20,000	Water at opening of Bath in morning	Water after a "men's" day	Water after a "ladies'" day
Bright	Bright	Bright	Bright	Bright	Bright	Bright	Bright	Bright	Bright
Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Faint Earthy	Faint Earthy	Faint Earthy	Faint Earthy	Faint Earthy	Faint Earthy	Slight Earthy	Slight Earthy	Slight Earthy	Slight Earthy
8.0	7.6	8.0	7.8	8.0	7.6	7.6	8.0	8.0	8.0
—	16.7	—	16.0	9.1	9.4	9.4	12.1	12.1	12.1
—	1.5	—	1.3	1.2	0.65	0.65	1.4	1.4	1.4
—	0.016	—	0.004	0.005	0.0072	0.0062	0.0076	0.0152	0.0250
—	0.014	—	0.010	0.016	0.011	0.012	0.0160	0.0176	0.0210
—	0.070	—	0.070	0.085	0.070	0.090	0.085	0.090	0.095
43	3,200	92	38	11	530	2,400	5	580	16,000
5	350	15	2	4	11	15	1	5	3,500
-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	+100 c.c.
-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.
-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.	-100 c.c.

or outlet end of bath.

suffices for the usual size of bacteriological sampling bottle. Bottles used for the collection of samples for chemical analysis must not, of course, contain "hypo." Alternatively, the inoculations of the bacteriological examination can be made immediately on collection of the sample, but this is seldom convenient.

As a measure of the cleanliness of the water and the efficiency of the purification plant, chemical analyses are of great value. We are of opinion that the water can be maintained at such a degree of cleanliness that:—

1. The albuminoid nitrogen does not exceed 0.025 part per 100,000.

2. The oxygen absorbed does not exceed 0.25 part per 100,000.

There is a progressive rise throughout the bathing season in the free ammonia and chlorides in the water, and the former is of importance in relation to chlorination. Also, as a result of continuous sulphate of alumina addition there is a rise in the sulphate or permanent hardness and a corresponding fall in the bicarbonate or temporary hardness. The *pH* value will also fall unless soda ash is appropriately added.

Some of the analytical results that we have obtained with bath waters purified by the continuous circulation system are shown in Table V.

Generally, our experience indicates that the system is satisfactory, and that these installations, properly constructed and operated, afford a very substantial measure of security against the contraction of disease by bathing. This security is obtained at a cost which experience has shown to be reasonable, and, in fact, less than the system of frequent emptying and refilling.

It has previously been noted, and is again emphasised, that the installation must be carefully designed, adequately planned, and efficiently operated. There is a tendency to instal plant with insufficient reserve capacity and this results in inferior purification of the water during times when the bathing load is unusually heavy.

Control of purification is maintained by repeated daily observations on the bath water in respect of its clarity, free chlorine content and *pH* value. These duties are entrusted to trained bath attendants who are provided with the necessary testing solutions and apparatus.

The free chlorine content of the water should also be frequently determined and care taken that nitrites are not mistaken for chlorine. Also, for reasons previously explained, it is important that frequent tests for the free ammonia content of the water should be made.

It is customary for the manufacturers of the purification plants to supply apparatus (comparators) for conducting the above tests. These are usually well arranged for the purpose and the tests can be applied with simplicity and sufficient accuracy.

Complete records should, of course, be kept in log-books regarding the treatment processes and control tests, together with other details of the establishment, such as number of bathers at each session, complaints, etc.

Algal growths are apt to prove a nuisance in swimming baths, and the dose of chlorine commonly used is inadequate to prevent entirely their development, particularly in outdoor pools. The frequent cleansing by brushes, etc., of the walls and bottom of the bath is a common measure of treatment employed, and, in other cases, copper sulphate is added to the water. The continuous addition of a dose of 1 to 2 parts per million of copper sulphate for a few days usually suffices to remove the algæ, but the treatment should be started at the first signs of growth. Algæ are less likely to develop if the *pH* value of the water is maintained in the 7.5 to 8.0 range.

Sterilisation of swimming bath water by ozonisation, ultra-violet

rays and katadyn silver has been attempted, but so far chlorination is the process most commonly employed in this country, in view of its comparative simplicity, efficiency and economy. It is unlikely to be supplanted by either ultra-violet rays or katadyn silver, neither of which is efficient in practice, but ozonisation has greater prospects of success. The latter process has been installed at a few places in this country, and, when certain plant difficulties have been overcome, further extensions are likely, particularly where the costs of electricity are low. Ozonisation has the advantages of rendering the water of very attractive colour and clarity, and, applied efficiently, the bacterial results are satisfactory. For successful operation, the water must be well filtered so that it is of reasonable clarity and organic purity, but, since ozone fairly rapidly disappears from the water, it is necessary to continue its addition to the water in order to maintain a satisfactory bacteriological condition throughout the bath. In some systems, the ozone is, therefore, admitted at the bottom of the bath by a series of distributing pipes and apertures set in the floor, and the bubbles of gas can be seen rising to the surface of the water. In such baths, most attractive conditions of the water prevail and a high standard of bacterial purity is maintained. It is necessary, however, to adjust the ozone discharge carefully so as to avoid an excess in the atmosphere, which causes unpleasant odour and discomfort to the bathers and onlookers.

Ozonisation has the disadvantages that it requires a somewhat complicated plant, liable to break down, and requiring fairly frequent skilled attention. Also, it suffers from the reproach that, if the electricity supply fails, the process comes to a standstill, but this can be overcome by the installation of a stand-by alternative source of electric supply. In some cases, a chlorinating plant is kept as a stand-by. Ozonisation is more costly than chlorination, but the costs may not be prohibitive or incommensurate with the advantages gained. No simple method of determining the amount of ozone present in the water is available, but the starch-iodide test, in neutral solution, is employed to demonstrate its presence.

The following publications dealing with the construction and operation of swimming baths should be consulted by those interested in the subject :—

“The Purification of the Water of Swimming Baths,” 1929, issued by the Ministry of Health.

“Swimming Bath Water Purification,” 1929, by F. Wilkinson and F. J. Forty.

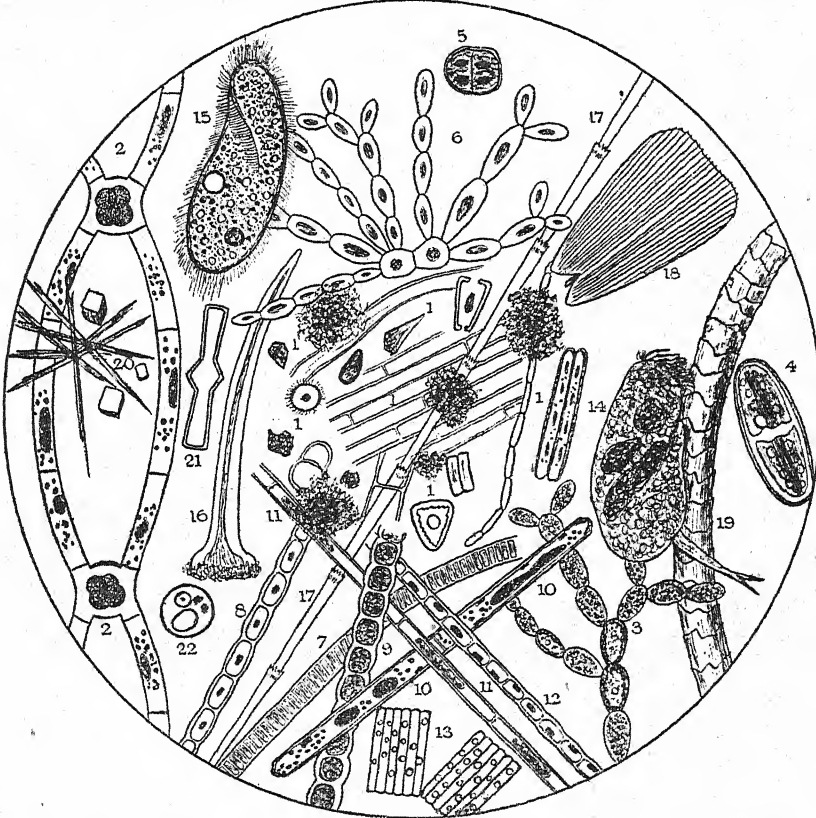
“Swimming Pools and Other Public Bathing Places,” *American Journal of Public Health*, December, 1926.

PLATES

PLATE I

The forms shown on this plate were contained in a sample of water from a stream on Dartmoor which was used in its unfiltered condition for the supply of a small town. After heavy rains the town supply contained visible particles, sufficient in number to cause complaints to be received from the consumers. A sample of the water from the stream feeding the reservoir supplying the town, and afterwards the water which came from the mains during a period of heavy rainfall were submitted for examination.

The deposit from the brook water contained a number of organisms, vegetable débris, etc., characteristic of water from such sources.



1. Vegetable débris—remains of cells, fragments of diatoms.
2. *Staurospermum viride*. F.W.A.¹ N.O. *Zygophyceæ*.
3. *Lemanea torulosa*. F.W.A. N.O. *Lemaneaceæ*.
4. Desmid. F.W.A. Species of *Penium*.
5. *Pleurococcus*. F.W.A. N.O. *Palmellaceæ*.
6. Dead form of 3. Cells plasmolysed.
7. *Ulothrix tenuis*. F.W.A. N.O. *Ulotrichææ*.
- 8-12. Various forms of algal filaments. 9 is evidently a species of *Ulothrix*. 10 was motile.
13. Diatom. F.W.A. Sub-family *Fragilarieæ*.
14. A rotifer, or wheel animalcule. Animal of sub-kingdom *Annuloida*.
15. *Paramecium* (*Nassula*?). S.K. Protozoa. Class *Infusoria*.
16. An animal spine.
17. Hair of insect.
18. Wing scale of insect.
19. Fibre of wool.
20. Crystal; probably calcium sulphate.
21. Skeleton of a diatom.
22. Not identified. Free swimming, but no visible cilia.

All magnified 300 diameters.

¹ F.W.A. = Freshwater Algae.

PLATE II

The first twenty organisms on this plate were found in the water from the mains supplied by the reservoir referred to in Plate I. It is obvious that water from such a source should not be supplied without prior filtration.

1-6. Various kinds of desmids :

1. *Euastrum pinnatum*. 2. *Penium Brébissonii*. 3. *Closterium Leib-
leini*. 3a. *Docidium hirsutum*. 4 & 6. Species of *Staurastrum*.
5. *Arthrodesmus convergens*.

7-11. Various kinds of diatoms :

- 7, 8, & 9. Species of *Fragilaria*. 10. Dead *Pinnularia*. 11. A *Pinnu-
laria* (?).
12. An infusorian in resting stage.
13. *Actinophrys* Sol. S.K. Protozoa. Class Rhizopoda.
14. A species of *Paramœcium*. S.K. Protozoa. Class Infusoria.
15. An algal zoospore.
16. Species of *Anguillula*. A nematode worm.
17. A rotifer.
18. Species of *Mesocarpus*. F.W.A.
19. Species of *Ulothrix*. F.W.A.
20. Vegetable tissue.

Figs. 20a to 29 are from another moorland water supply. All were found in a sample taken from the town mains (N. Wales).

- 20a, 21, 22. Ciliated animalcula.
23. Probably a spirostomum. N.O. Ciliata.
24. *Crenothrix*. (*Vide* Plate XVIII., Nos. 7a, 7b.)
25. *Actinophrys* Sol.
26. A rotifer (*Ecistes*).
27. Large infusorian.
28. Rotifer with cilia withdrawn.
29. A small infusorian with long cilium, attached like a vorticella.

All magnified 300 diameters.

PLATE II

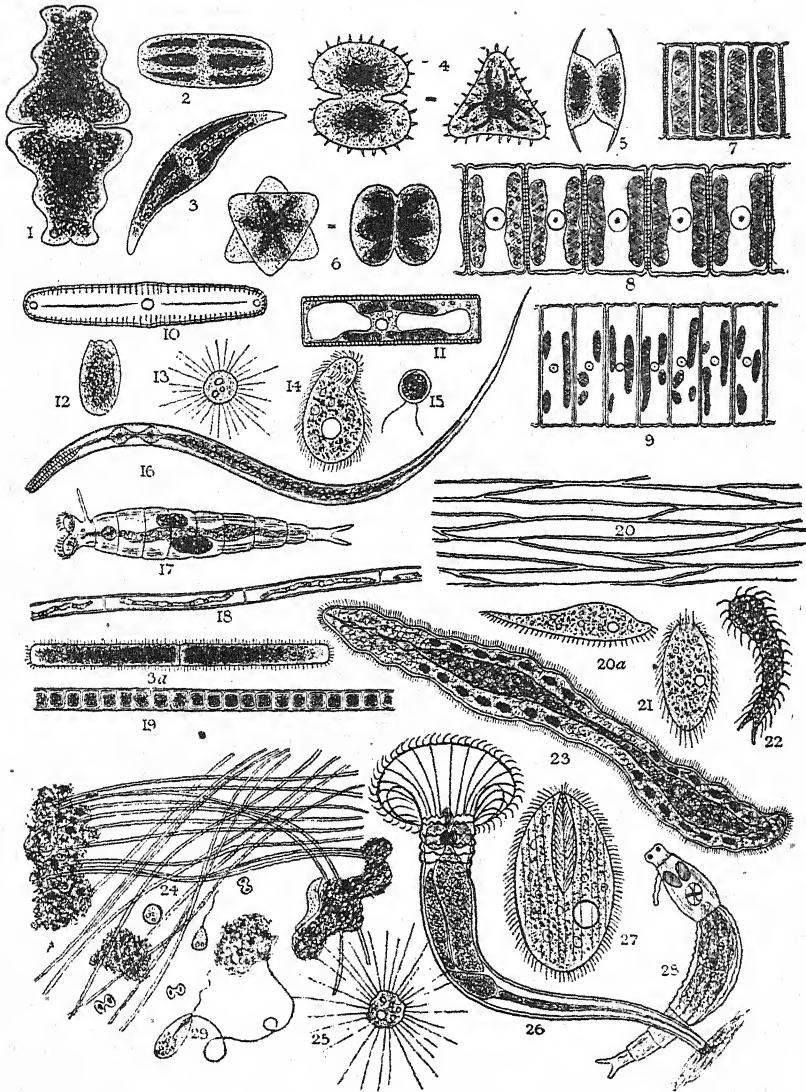
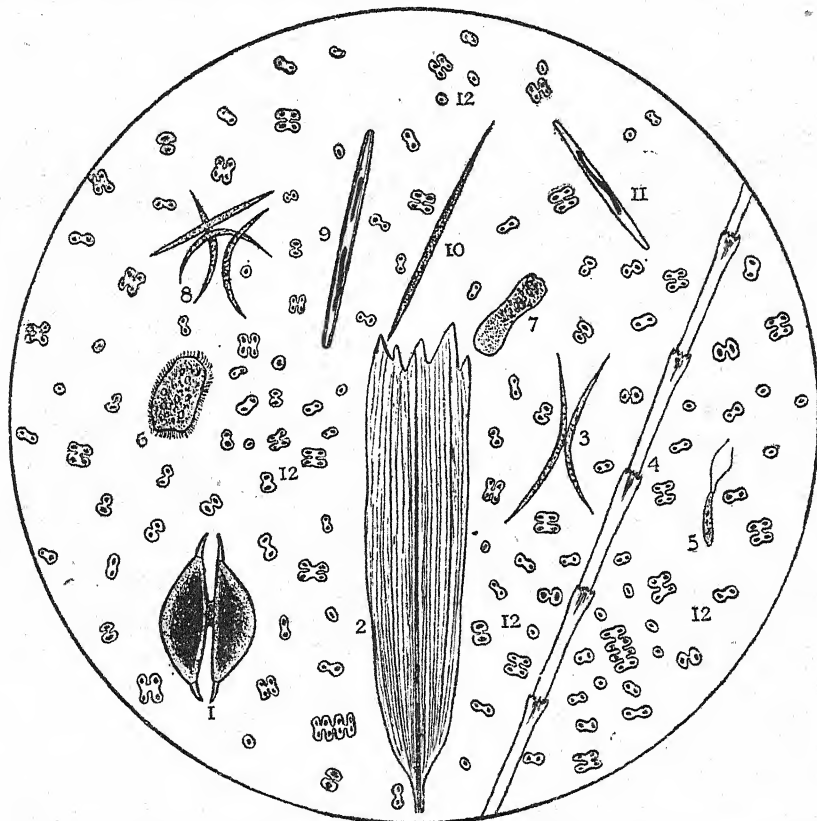




PLATE III

At a later date the water referred to in the description of Plate II., Nos. 20a-29, became quite green in appearance, and acquired, when warmed, a disagreeable odour. The water was found to be swarming with a pleurococcus, and to the death and decay of this organism was attributed the odour observed. The water formed a green deposit in any jug or vessel in which it was left, and in glass vessels exposed to light the pleurococcus grew luxuriantly.



1. A desmid (*Arthrodesmus*).
2. Scale from wing of moth or butterfly.
3. A desmid (*Ankistrodesmus*).
4. Hair of insect.
5. Minute protozoon.
6. A ciliate infusorian.
7. An amœba.
8. As fig. 3.
- 9 & 11. Diatoms.
10. A small desmid.

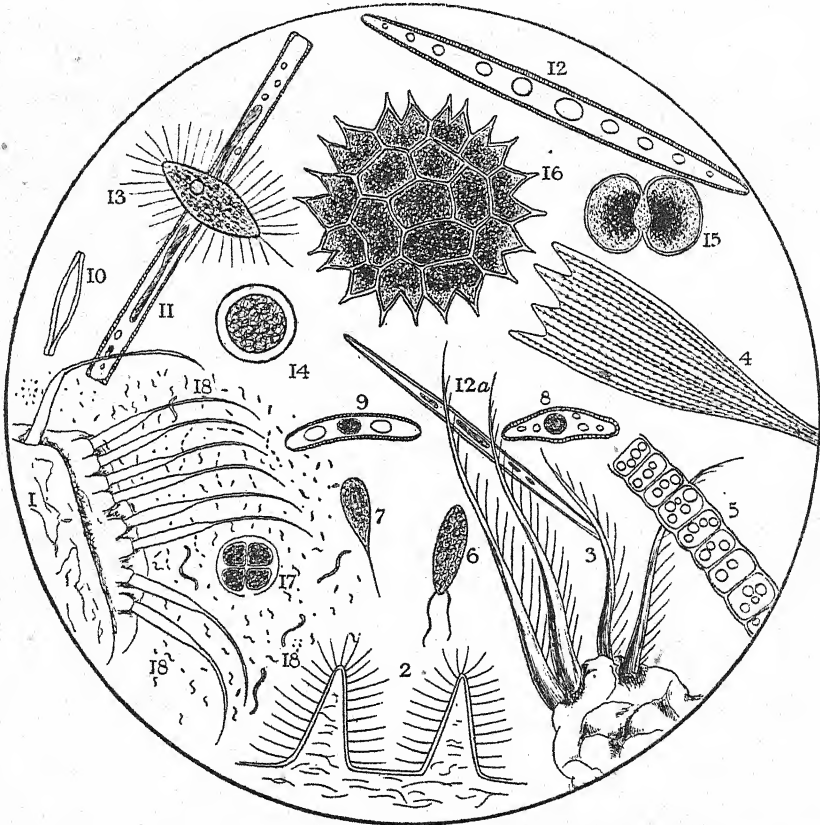
12. *Pleurococcus*. The members of this genus of the order *Palmellaceæ* are very frequently found in waters. The description of the genus given by Cooke is: "Cells gregarious, globose, or angular; single or associated in small families. Cell-contents green, or oily red. Multiplication by division in alternate directions. Propagation by gonidia."

All magnified 300 diameters.

PLATE IV

Deposit Found in a Water Reservoir

The organisms, etc., shown in this plate were found in water from an uncovered service reservoir. Complaints had been received of "insects" being found in the water drawn from the house taps. Upon examining the service reservoir an accumulation of debris was found in it. We advised that the reservoir should be covered and ventilated in such a way as to prevent access of light.



- 1, 2, 3. Fragments of animal tissue.
4. Scale from wing of moth or butterfly.
5. Dead algal filament.
- 6 & 7. Ciliated monads. S.K. Protozoa. Class Infusoria.
- 8-12a. Various diatoms.

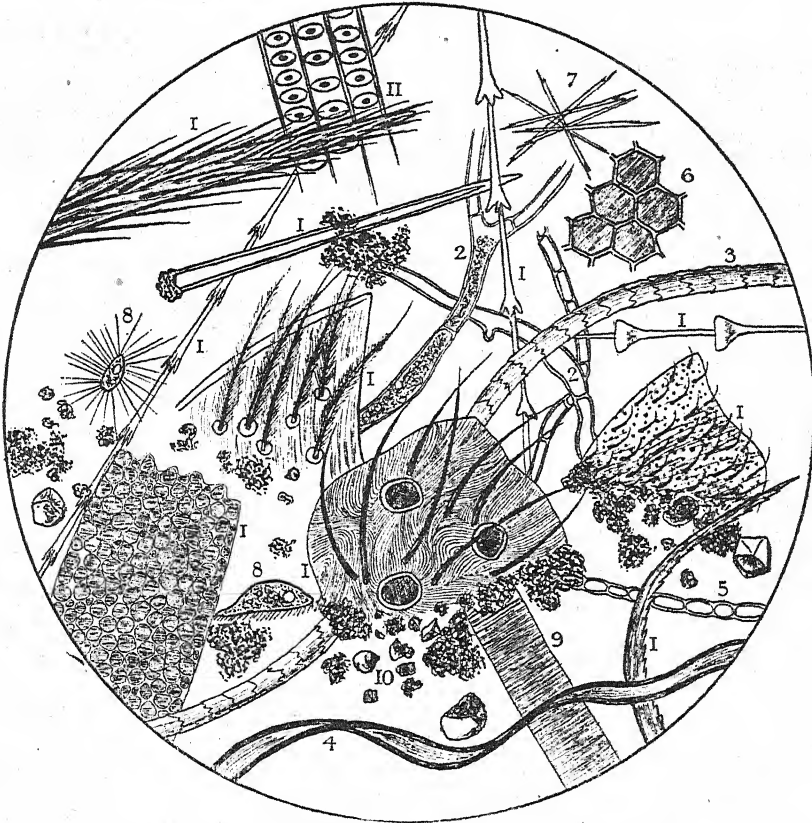
13. A very active infusorian; probably Halteria.
14. An encysted form of infusorian.
15. Cosmarium (a desmid).
16. Pediatrum (discoidal desmid).
17. Pleurococcus undergoing division.
18. Various bacteria (spirilla, bacilli, and micrococci).

1-4 magnified about 50 diameters.
5-18 magnified about 300 diameters.

PLATE V

Sample of Water from an Uncovered House Cistern

Cases of typhoid fever having occurred in a group of houses near a sewage works and dust shoot, the houses were examined and found to have small uncovered cisterns in the sculleries. The water from one of these cisterns was sent for bacteriological examination and found to be very unsatisfactory, containing *Bact. coli* in appreciable number. The deposit present in the water, when examined microscopically, was found to contain remains of insect life. Quite possibly many of these insects had been hatched in the refuse heaps.



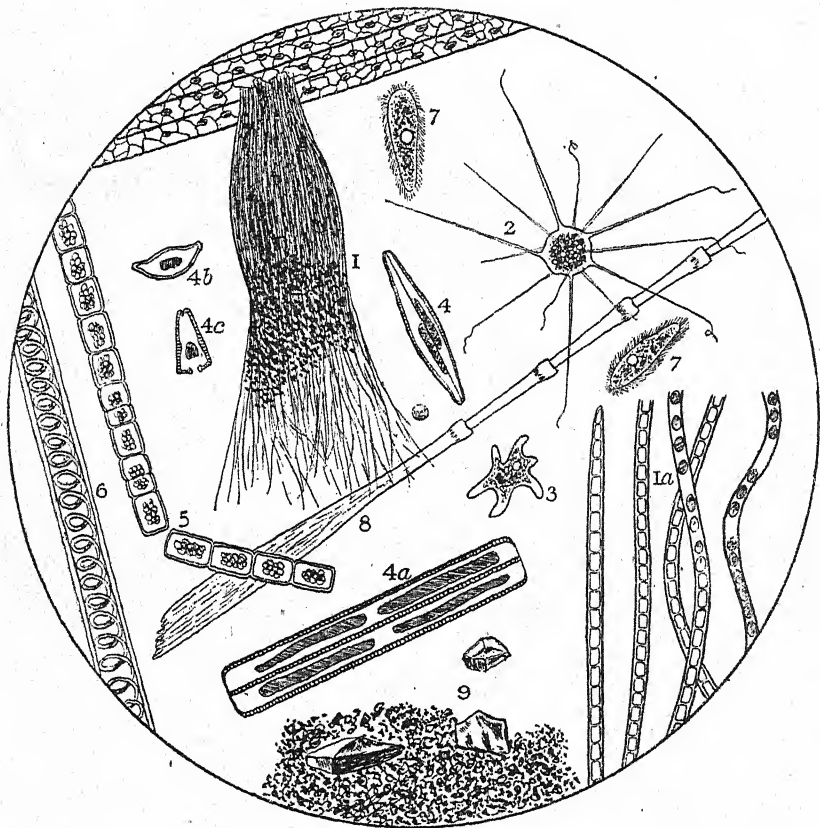
- | | |
|--|---------------------------------------|
| 1. Hairs, appendages, and wing-cases of various animals. | 6. Portion of eye of insect. |
| 2. Fungal hyphæ. | 7. Crystals of calcium sulphate. |
| 3. Wool fibre. | 8. A ciliate animalcule. |
| 4. Cotton fibre. | 9. Probably the trachea of an insect. |
| 5. Dead algal filaments. | 10. Sand and mineral debris. |
| | 11. Wood of conifer. |

1 & 10 magnified about 50 diameters.
2-9 highly magnified.

PLATE VI

Water from River Below a Small Dye-works

This river water was not obviously polluted, though complaints were occasionally made of unpleasant odours arising in the vicinity, and attributed to the effluent from the dye-works. This effluent had been treated chemically and contained a trace of iron. *Crenothrix* was found to be flourishing in the water. It occurs chiefly in water containing a little organic matter in solution together with a trace of iron.



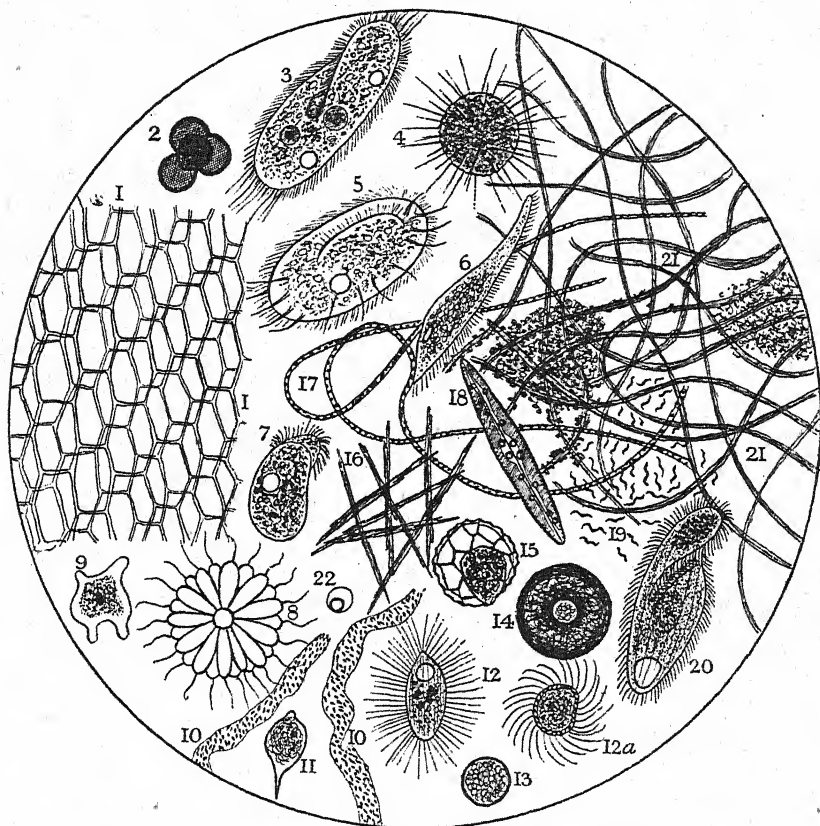
1. *Crenothrix polyspora*. Tuft attached to dead leaf.
- 1a. *Crenothrix polyspora*. Portion of this fungus more highly magnified, showing spore formation. *Vide* Plate XVIII.
2. Probably an artodiscus without contractile vacuole. S.K. Protozoa Class Rhizopoda.
3. An amoeba.
- 4, 4a, 4b, 4c. Various diatoms.
5. Algal filament (*Ulothrix*). Cells in act of dividing.
6. Spiral vessel of flowering plant.
7. Small paramoecium.
8. Hair of insect.
9. Particles of sand embedded in vegetable debris.

No. 1 magnified 20 diameters, 1a about 500 diameters, the others about 250 diameters.

PLATE VII

A Sewage Polluted River Water

This may be taken as typical of a grossly polluted water. The sewage had flowed over a small area of land, and had undergone no process of treatment or filtration.



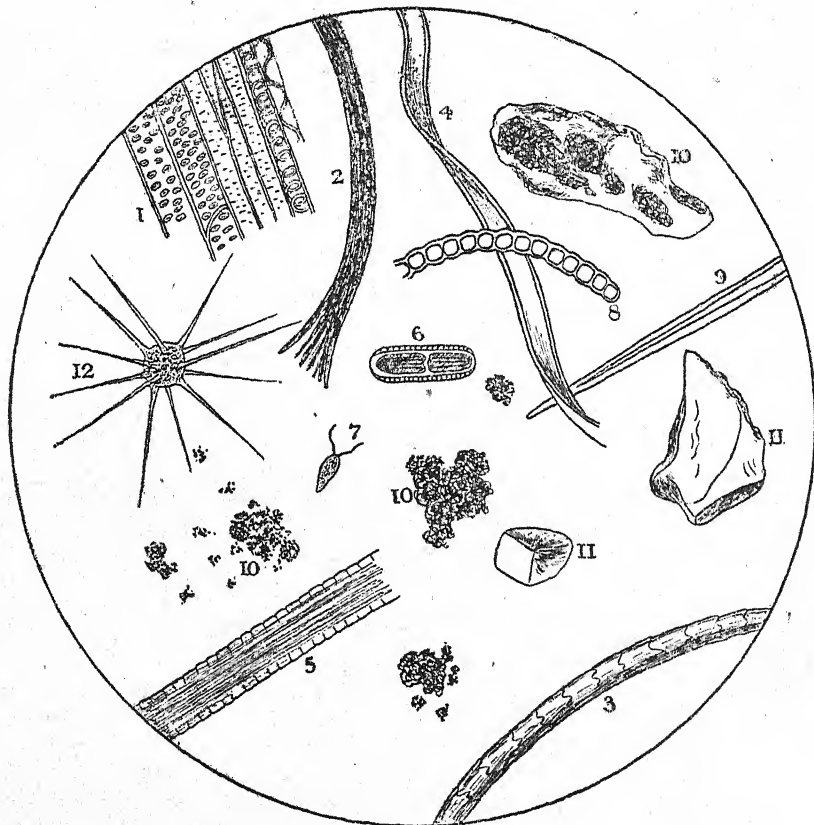
1. Pith cells of a flowering plant.
2. Tetrahedral spores ?
3. Species of *Stylonychia*. A ciliate infusorian.
4. One of the *Heliozoa*. S.K. Protozoa. Class Rhizopoda.
5. *Euplotes vannus*. An infusorian.
6. *Oxytricha gibba*. An infusorian.
7. A ciliate infusorian.
8. *Synura uvella*. A confervoid alga.
9. A lobose amoeba.
10. Gelatinous mass of bacteria.
11. *Euglena viridis*. A ciliate infusorian.
12. A very active infusorian (*Halteria*?).
- 12a. The same at rest.
13. Egg of an entozoon.
14. Arcella. S.K. Protozoa. Class Rhizopoda.
15. Probably an encysted form of some protozoon.
16. Crystals of calcium sulphate.
17. *Beggiatoa alba*.
18. Diatom (*Navicula*).
19. Spirilla.
20. *Leucophrys spathula* (ciliated infusorian).
21. Mass of fungal hyphae with vegetable debris.
22. ? Motile, with highly refractive spot.

Magnified about 300 diameters.

PLATE VIII

Deposit on the Side of a Well

When examining a well, the water from which showed, bacteriologically and microscopically, but not chemically, certain signs of pollution, a little discoloration was observed on the brickwork near the point where the pump pipe entered the well. The microscopical examination of this proved that impure water was entering at this spot, and it was doubtless derived from slop water which was poured down the defective drain near the pump.



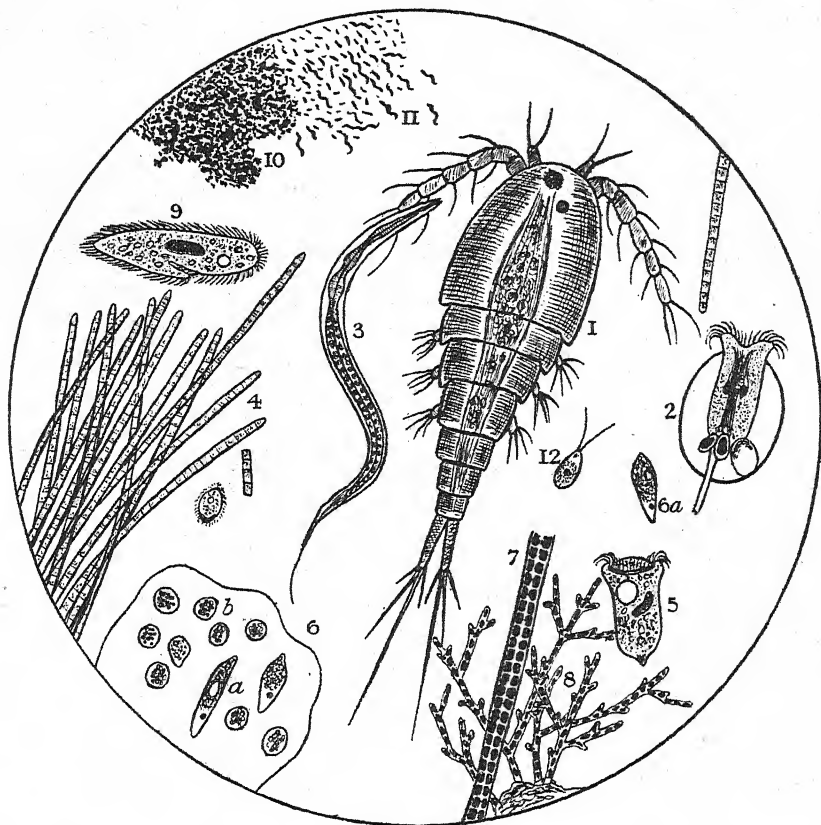
- | | |
|--|--|
| 1. Various wood cells from some dicotyledon. | 7. A zoospore. |
| 2. Fibre of hemp. | 8. Dead algal filament. |
| 3. Fibre of wool. | 9. Animal spine. |
| 4. Fibre of cotton. | 10. Particles of clay and brick. |
| 5. Probably the hair of some animal. | 11. Particle of sand. |
| 6. A desmid (Penium). | 12. A Radiolarian. S.K. Protozoa. Class Rhizopoda. |

Magnified about 300 diameters.

PLATE IX

Water from a Small Stream Receiving the Overflow from a Cesspool

This water is typical of many in rural districts. Only a very few of the multitude of organisms found in the water are here depicted.



1. A cyclops. These small crustaceans abound in ponds and ditches.
2. A rotifer in sheath, with cilia expanded.
3. A nematode or round-worm.
4. Oscillatoria of dark blue green colour, with oscillatory and sinuous movements. Attached to debris floating on the water. Probably Oscillatoria antliaria.
5. A free-swimming Vorticella.
6. Euglena viridis in a gelatinous sheath. (a) In motion; (b) at rest.
7. Green algal filament.
8. A dark green branching alga (Microthamnion?).
9. Paramoecium Aurelia.
10. Vegetable debris with
11. Spirilla and bacilli.
12. Zoospore of alga with cilia and eyespot.

1, 2 & 3 magnified about 50 diameters, the others 300 diameters.

PLATE X

Organisms from Various Sources

1. *Gammarus pulex*. A crustacean very prevalent in waters rich in vegetable matter.
2. Two species of *Vorticella* attached to portion of the body of a *Gammarus*.
3. *Euplotes Charon*, side view. 3a The same organism, ventral aspect.

The above were found in a well water, and proved the presence of surface pollution.

-
4. A large infusorian. 4a. The same, contracted.
 5. The encysted form of some infusorian.
 6. *Beggiatoa alba*.

These were found in the effluent from a sewage works.

-
7. A rotifer (*Floscularia ornata*) in sheath. 7a. Same extended, showing cilia
 8. *Macrobiotus* or water bear, containing ova, 8a.
 9. Larva of gnat.

From a rainwater tank.

-
- 10 & 11. Diatoms (*Surirella* and *Pleurosigma*).
 12. A desmid (*Closterium*).
 13. A large form of *Oscillatoria*.

From River Blackwater. Pollution slight.

Nos. 1 & 9 magnified about 10 diameters, the others about 250 diameters.

PLATE X

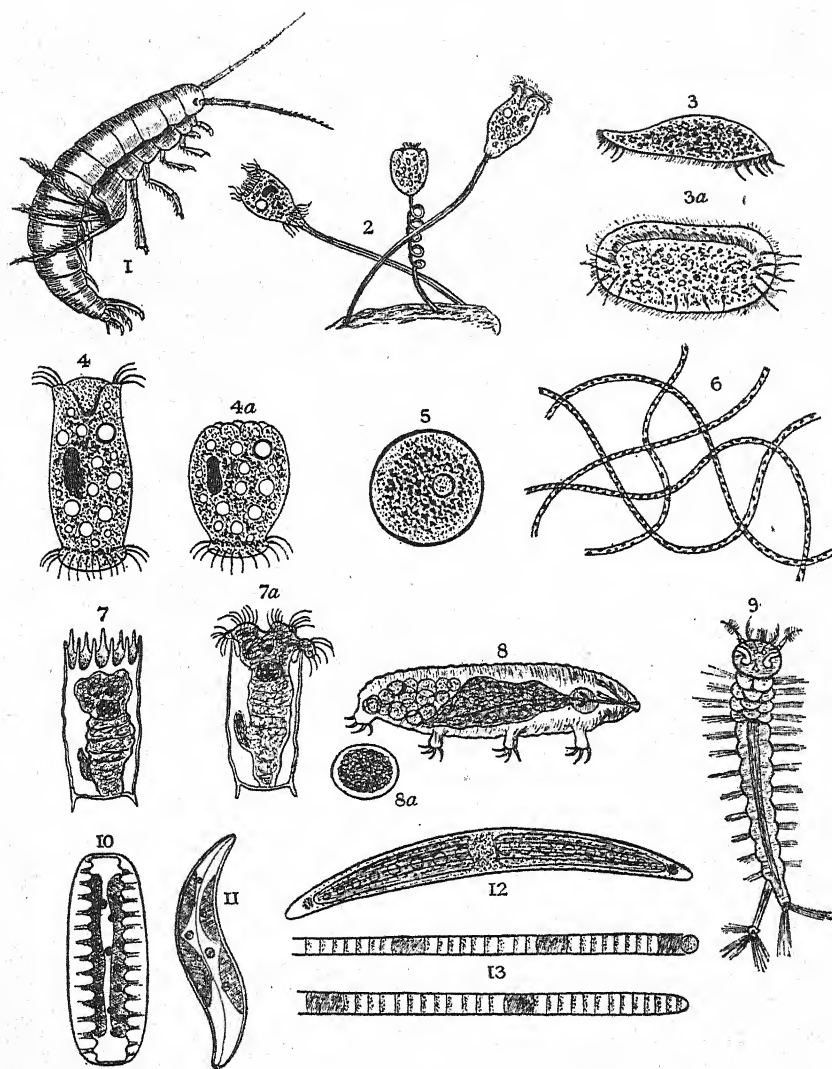
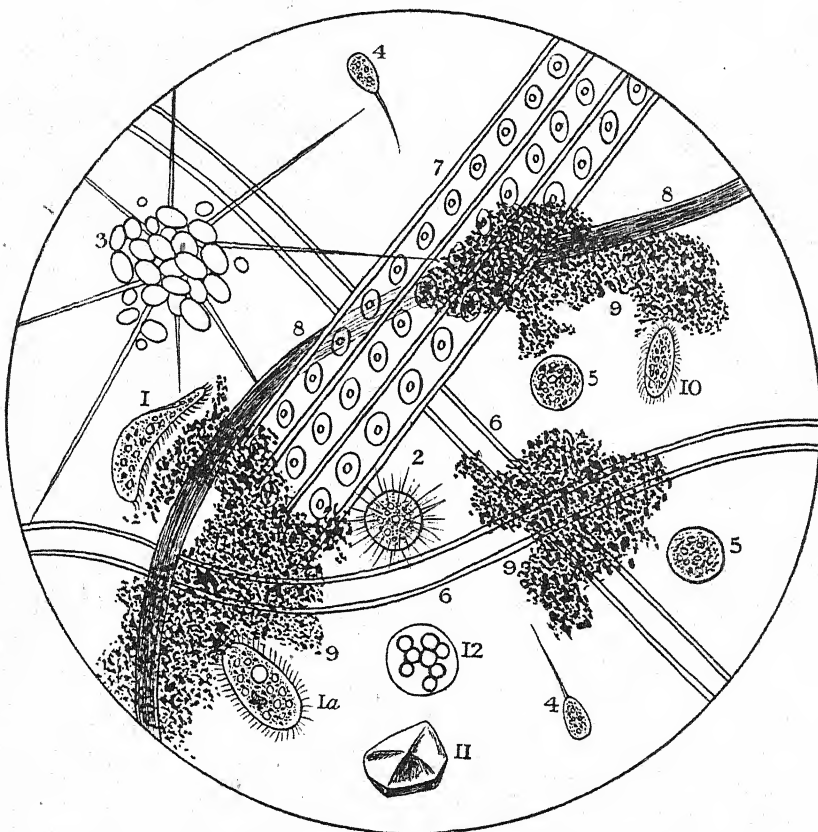


PLATE XI

Shallow Well Water

This water contained a good deal of particulate matter which settled to the bottom of the containing vessel in reddish floccules. It was obviously of very unsatisfactory character. The microscope showed the presence of oxide of iron, and of animal and vegetable débris denoting pollution.



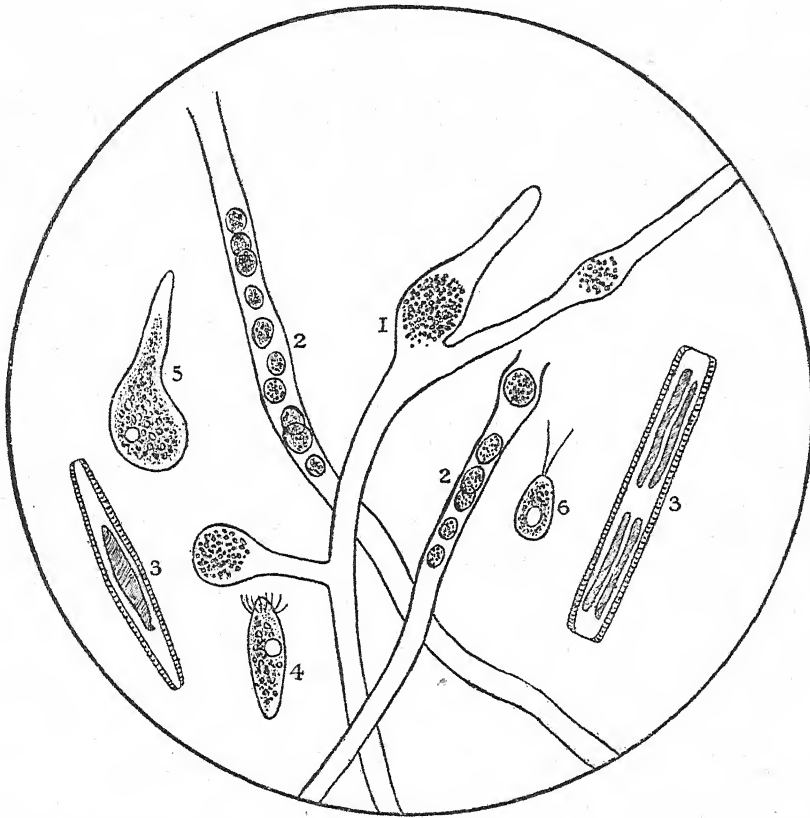
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|---|---|
| 1. Paramœcium, side view. 1a. Same, surface view. | 7. Fragment of conifer. |
| 2. Acanthocystis, one of the Heliozoa. | 8. A hair. Very opaque, bluish tinge. |
| 3. Aphanochaete (dead). | 9. Vegetable débris with ferric hydrate. |
| 4. Zoospore of alga. | 10. A small paramœcium. |
| 5. Encysted form of some protozoa. | 11. Particle of sand. |
| 6. Vegetable fibre. | 12. A slightly motile organism with very refractive granules. |

All magnified about 300 diameters.

PLATE XII

Water from a Shallow Well

This water, good chemically, contained a very little flocculent matter which under the microscope revealed the undermentioned forms. Obviously the well had some defect.



1 & 2. Fungal hyphae, with spores. This constituted the particles of flocculent matter seen in the water when held up to the light.

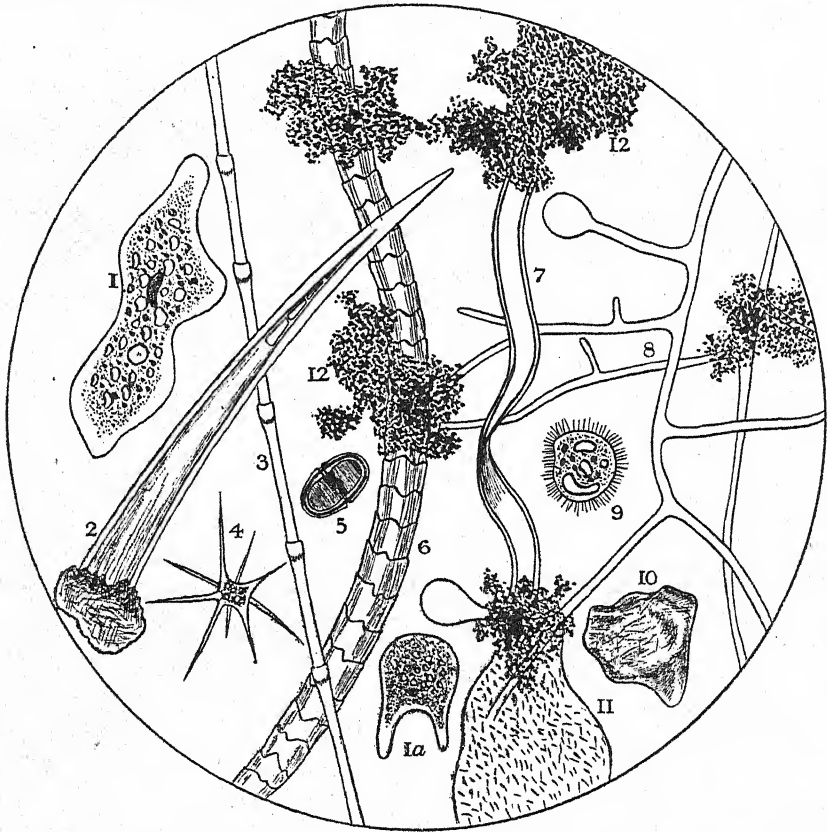
3. Diatoms.
4. Species of infusorian.
5. An amoeba (Lobosa).
6. Zoospore of alga.

Nos. 1 & 2 magnified about 500 diameters, the others about 250.

PLATE XIII

Water from a Shallow Well

This water was chemically and bacteriologically impure. It was undoubtedly polluted with sewage matter.



1. Large amœba (Lobosa).
- 1a. A smaller form.
2. Animal spine.
3. Hair of some insect.
4. A form of Protomyxa.
5. A teleutospore.
6. Fibre of wool.

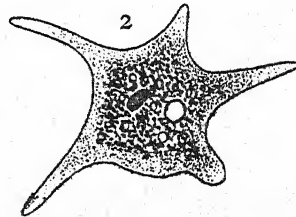
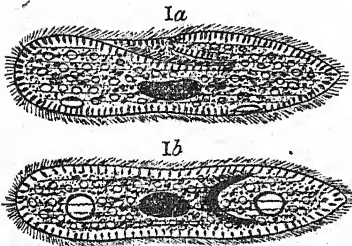
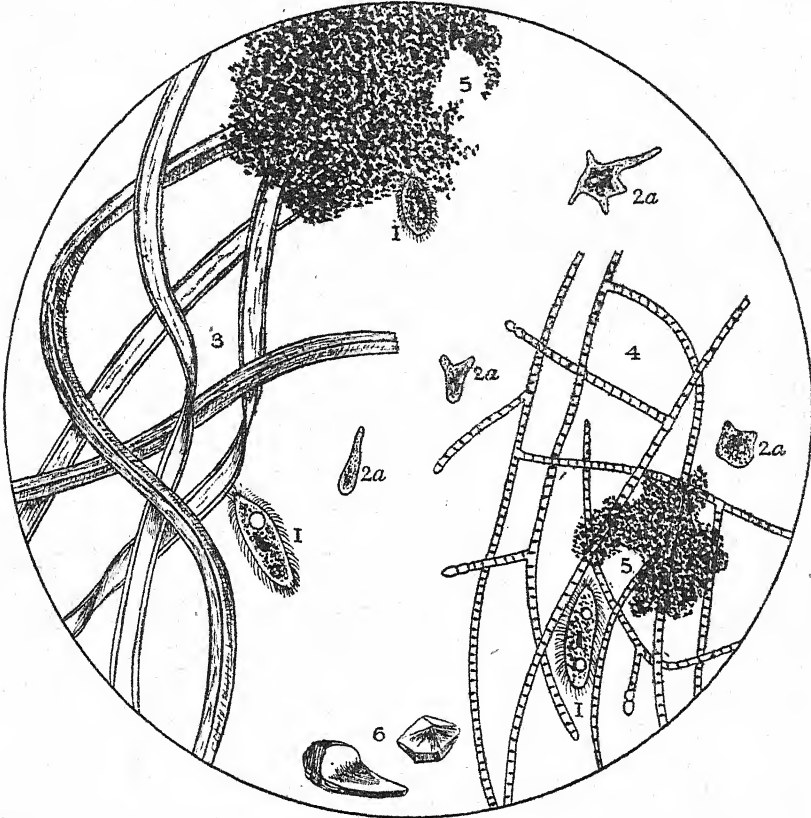
7. Vegetable fibre.
8. Fungal hyphæ, probably Saprolegnia.
9. Actinophrys.
10. Sand particle.
11. Zoogloea of bacteria.
12. Vegetable débris.

Magnified about 300 diameters.

PLATE XIV

Water from a Deep Well

This water came from a bored well, about 120 feet deep. The upper 20 feet was dug and lined with brickwork. About 20 yards away there was a tidal river, and there was a suspicion that either tidal water or subsoil water was entering the well. When, at a later date, the water was pumped out, a great quantity of water was seen to enter the well through defects in the brickwork. This confirmed the opinion formed from the examination of the water.



1. *Paramecia*.
- 1a. *Paramecium Aurelia*. { The vacuoles
Side view. { open and
1b. *Paramecium Aurelia*. { close alter-
Surface view. { nately.
2. An amoeba.

- 2a. Various amoeba.
3. Human hair and vegetable fibres.
4. Fungal hyphae, forming spores.
5. Decaying vegetable debris.
6. Particles of sand.

1-6 magnified about 250 diameters.
1a, 1b & 2 more highly magnified.

PLATE XV

A Small Public Water Supply

This supply was derived from two sources, one a deep well, the other a spring. During the autumn particles of matter resembling boiled potato were found in the water from house taps, and when the mains were flushed large masses of this material appeared.

Chemically the water was found to be satisfactory, but biologically and bacteriologically it was decidedly unsatisfactory.

After standing some days the water acquired an offensive odour. By persistent flushing of the mains the growth disappeared, and no trouble has since been experienced.

1. Zooglœa of micrococci; 1a, each with a distinct gelatinous envelope.
- 2a, 3a, & 4a. Organism embedded in the zooglœa; some also, 2, 3, & 4, seen floating free in the water.
- 5 & 6. Anguillulæ. N.O. Nematoda.
7. Diatoms, very abundant in the zooglœa.
8. Algal threads.
9. Vorticella.
10. Apparently vegetable débris. It was of a red-brown tint, and contained a trace of iron.

PLATE XV

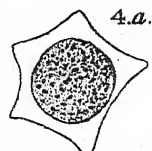
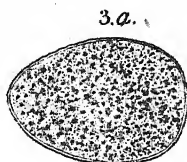
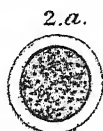
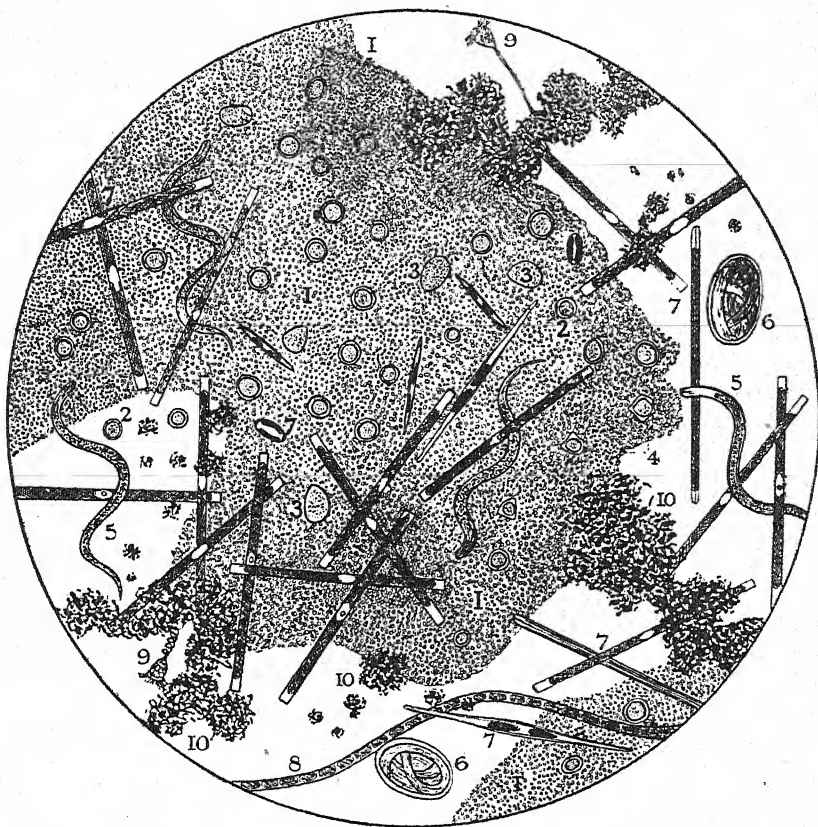
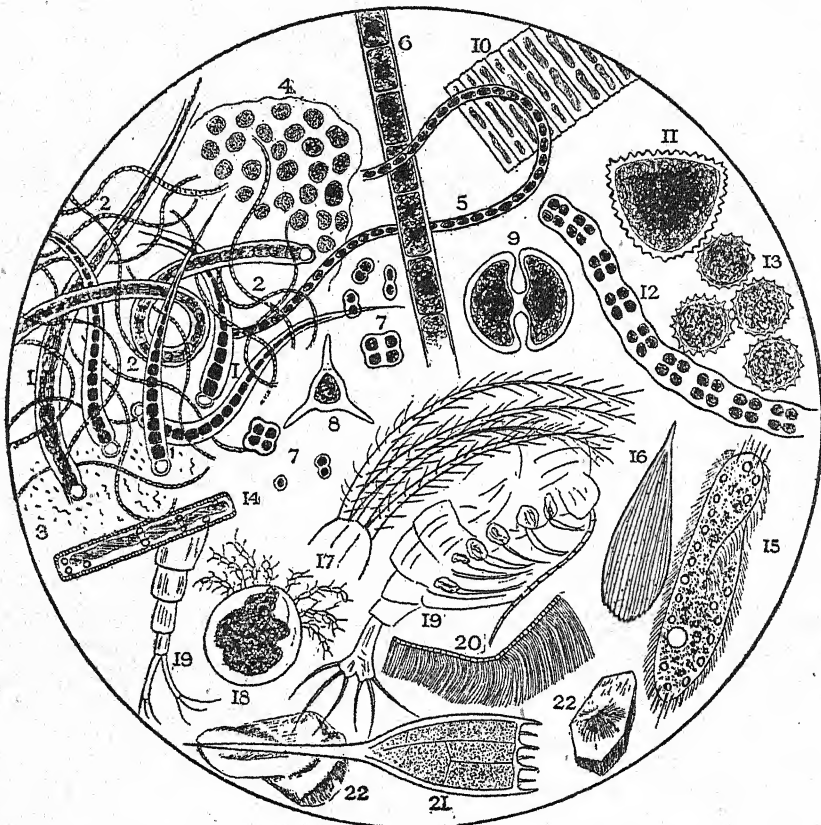


PLATE XVI

Scrapings from the Surface of a Slow Sand Filter

Some of the water was derived from springs and the remainder was collected from the surface of partly cultivated land. The surface of the sand filter, when dried, was found to be covered with a thin, semi-transparent, brownish-green film.



- | | |
|--|--|
| 1. Rivularia and allied forms, which with | 10. A diatom (Fragilariae). |
| 2. Beggiatoa formed the larger portion of the felted mass covering the sand. | 11. A desmid. |
| 3. Bacilli and spirilla. | 12. An algal filament. |
| 4. Palmella embedded in jelly. | 13. Probably pollen. |
| 5. A conferva. | 14. Diatom (Pinnularia). |
| 6. Probably a species of Zygnema. | 15. Stylonychia. |
| 7. Pleurococcus. | 16-20. Dead and disorganised animal remains. (16. Scale from wing of moth. 18. A mite. 19. Cyclops.) |
| 8. A desmid (Staurastrum). | 21. Sheath of rotifer. |
| 9. A desmid (Cosmarium). | 22. Sand particles. |

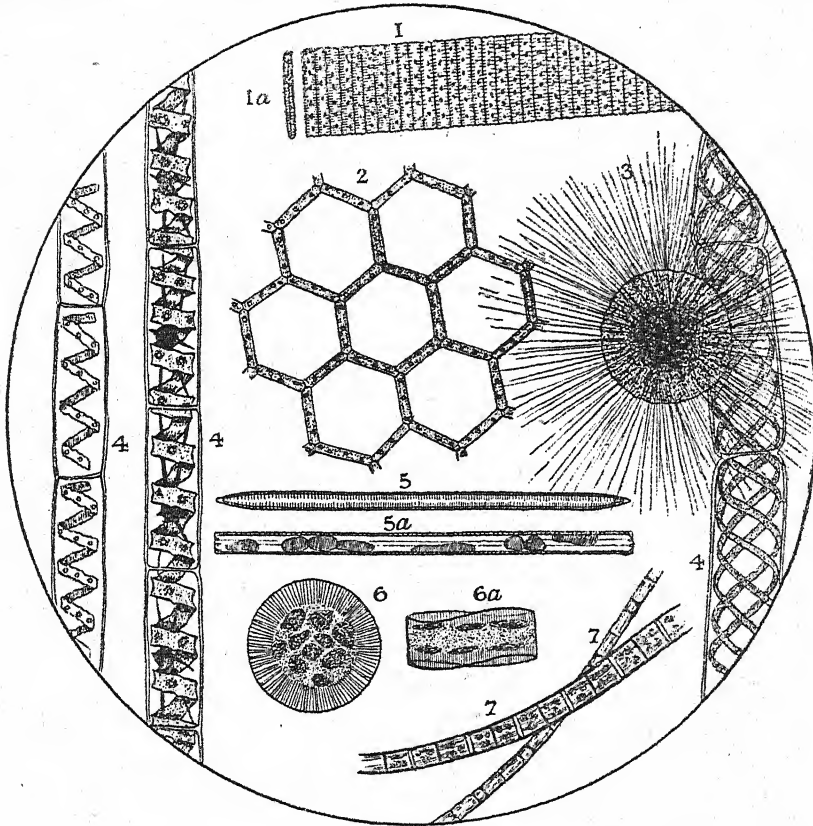
1-15 magnified about 100 diameters.

16-21 magnified about 50 diameters.

PLATE XVII

Scrapings from the Surface of a Slow Sand Filter

This water supply was derived from a large reservoir impounding upland surface water. The plate contains only a few of the organisms identified, but these were the most abundant. There was also much vegetable debris, not shown in the drawing.



1. Bands of diatoms (*Fragilaria*).
Girdle view.

1a. Separate diatom. Valve view.

2. *Hydrodictyon*. This organism is considered by some to be a desmid, in which the cells after division remain connected and form a network. It is a freshwater alga. Cooke regards it as a sub-family of the *Palmellaceae*.

3. *Actinosphaerium*. A rhizopod.

4. Filaments of a *Spirogyra*.

5. Diatom (*Synedra*). Valve view.

5a. Diatom (*Synedra*). Girdle view.

6. *Cyclotella*, a discoid diatom. Valve view.

6a. *Cyclotella*, a discoid diatom. Girdle view.

7. *Melosira*. Discoidal diatoms forming filaments. Closely allied to No. 6.

Nos. 2 & 3 magnified 100 diameters; No. 4, 200 diameters; Nos. 1, 5 & 7, 250 diameters; No. 6, 500 diameters.

PLATE XVIII

Organisms from Various Sources

1. *Anabæna*. Family Nostocaceæ. From a water with an odour of horse manure.
2. *Beggiatoa alba*. From outfall of a land drain from a sewage farm.
3. A species of *Nostoc*. From a ditch water. Said sometimes to cause water to become odorous.
4. *Sphærotilus natans*. (a) Natural size; (b) an enlarged thread. From a stream polluted with sewage and trade-waste.
5. *Conferva bombycina*. From a pond water.
6. *Spongilla fluviatilis*. (a) Natural size on twig; (b) spicules; (c) animal cells forming the sarcode of the sponge. From a mountain stream.
7. (a) Macro- and micro-spores of *Crenothrix polyspora*; (b) tufts of thread formed by germination of spores in parent thread. (Zopf.) *Vide* Plate II., No. 24.
8. *Volvox globator*. This organism was found in a reservoir, the water of which had fallen very low. The water developed a fishy odour.
9. *Leptomitrus lacteus*. From an impure river water.
10. *Cryptomonas*. From a pond water. This infusorian may impart to water an odour suggestive of violets.
11. *Bursaria gastris*. Said to have imparted a seaweed-like odour to water.
12. *Carchesium Lachmanni*. From luxuriant growth in sewage-polluted brook.
13. *Tabellaria*. A diatom which may impart an aromatic odour to water.
14. *Asterionella formosa*. A diatom which may impart an aromatic odour to water.
15. *Uroglena*, species of. Often mistaken for *Volvox*. May impart an "oily" or "fishy" odour to water.
16. Filament of a species of *Lyngbya*. A freshwater alga, may impart a disagreeable odour to water.
17. *Chara*. (a) showing reproductive organs. (b) *C. fragilis*, showing fertile and barren branches. (After Oliver.)

Nos. 8, 11 & 16 magnified 100 diameters. 17a slightly enlarged, 4a & 6a natural size, 17b slightly reduced. All others magnified 250 diameters.

PLATE XVIII

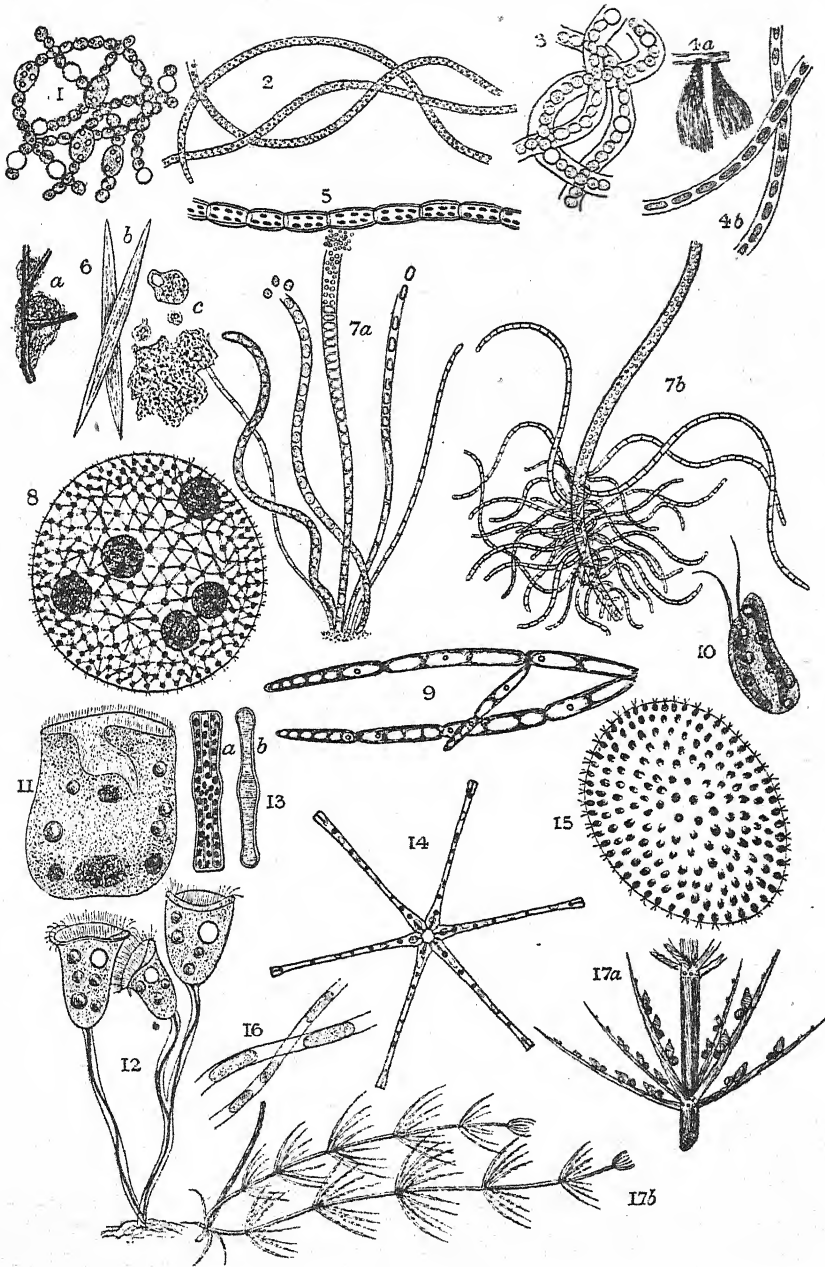
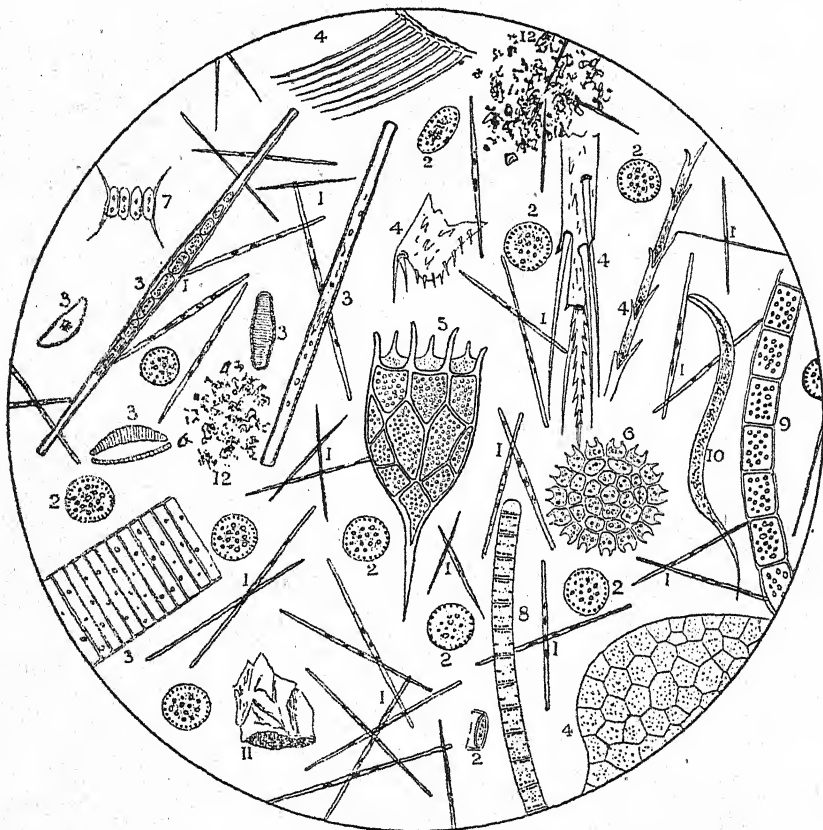


PLATE XIX

Sedimentary Matter Found in a Filtered Water

This was a moorland water passed through mechanical filters but complaints arose of discoloured turbid water.

The filters were not very efficient, but the growth was taking place in an open storage reservoir. When the filtered water ran directly into the mains, the trouble ceased. This course was continued until the reservoir could be cleaned and covered.



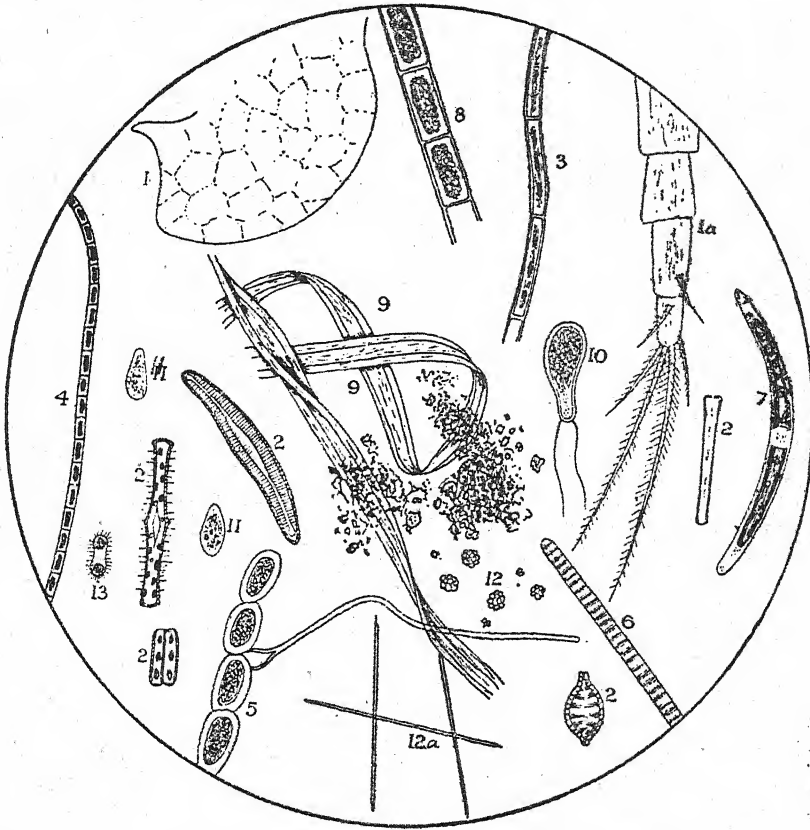
- | | |
|---------------------------------|-------------------------|
| 1. Diatoms. Navicula. | 7. Desmid. Scenedesmus. |
| 2. Diatoms. Stephanodiscus. | 8. Oscillaria. |
| 3. Diatoms. Various species. | 9. Algal thread. |
| 4. Remains of crustaceans. | 10. Anguillula. |
| 5. Sheath of a rotifer. Anurea. | 11. Sand. |
| 6. Desmid. Pediatrum. | 12. Organic debris. |

4 & 5 magnified about 100 diameters.
Others magnified about 300 diameters.

PLATE XX

Deposit from a Moorland Water

This water, derived from a river, was submitted to coarse sand filtration before supply to the consumers and the filtration was very imperfect. A marked deposit formed in a winchester quart sample of the water; in this deposit the forms of animal and vegetable life depicted upon the plate were observed.



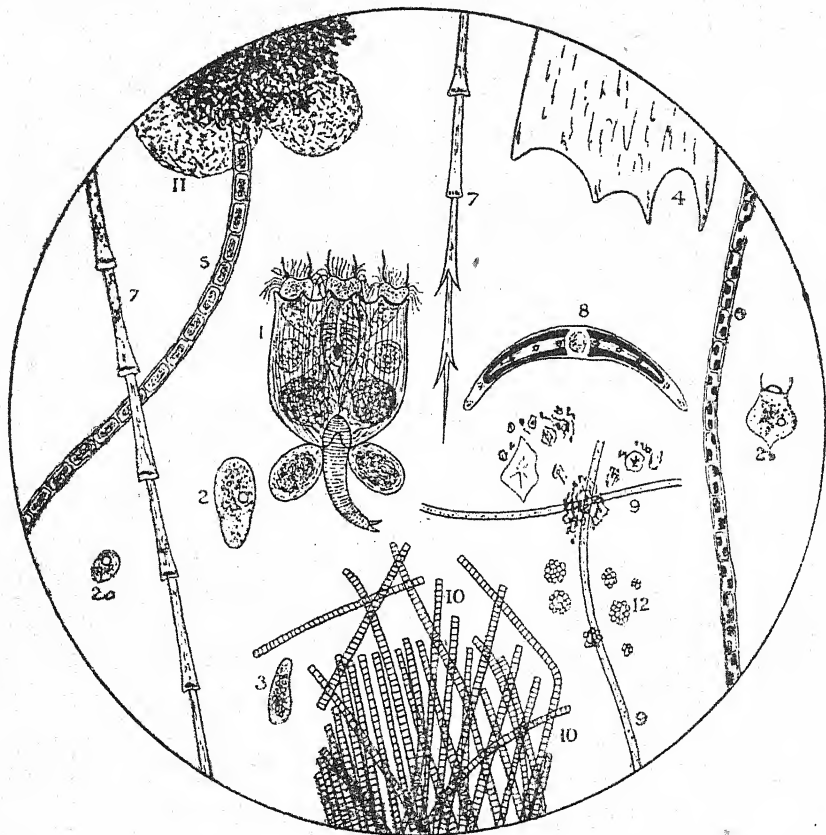
1. Carapace of a cyclops.
- 1a. Tail of a cyclops.
2. Diatoms.
- 3, 4 & 8. Algal threads.
5. Bulbochaete.
6. Oscillaria.

7. Desmid. Closterium.
9. Cotton fibre.
10. A large monad.
11. A very active infusorian.
- 12 & 12a. Crystals.
13. Probably a desmid.

No. 1 magnified 100 diameters; the remainder $\times 300$.

PLATE XXI

Lake or reservoir water proposed to be utilised for the supply of a town in South Wales. No sources of pollution on the gathering grounds but filtration was necessary.



- | | |
|---|---|
| 1. Rotifer (<i>Brachionus urceolata</i>) in sheath, with ova. | 4. Portion of carapace of some minute crustacean. |
| 2. Probably an amoeba (?). | 5 & 6. Algal threads. |
| 2a. A motile organism (?). No visible cilia. | 7. Hairs of insects. |
| 2b. An infusorian (?) | 8. Desmid. <i>Closterium</i> . |
| 3. An active and abundant infusorian. | 9. Fungus in debris. |
| | 10. <i>Oscillaria</i> in masses. |
| | 11. Zoogloea of bacteria. |

No. 1 magnified about 60 diameters.
Others magnified about 250 diameters.

PLATE XXII

A cyclops-infested water supply. Source from upland surfaces. Water not filtered before delivery.

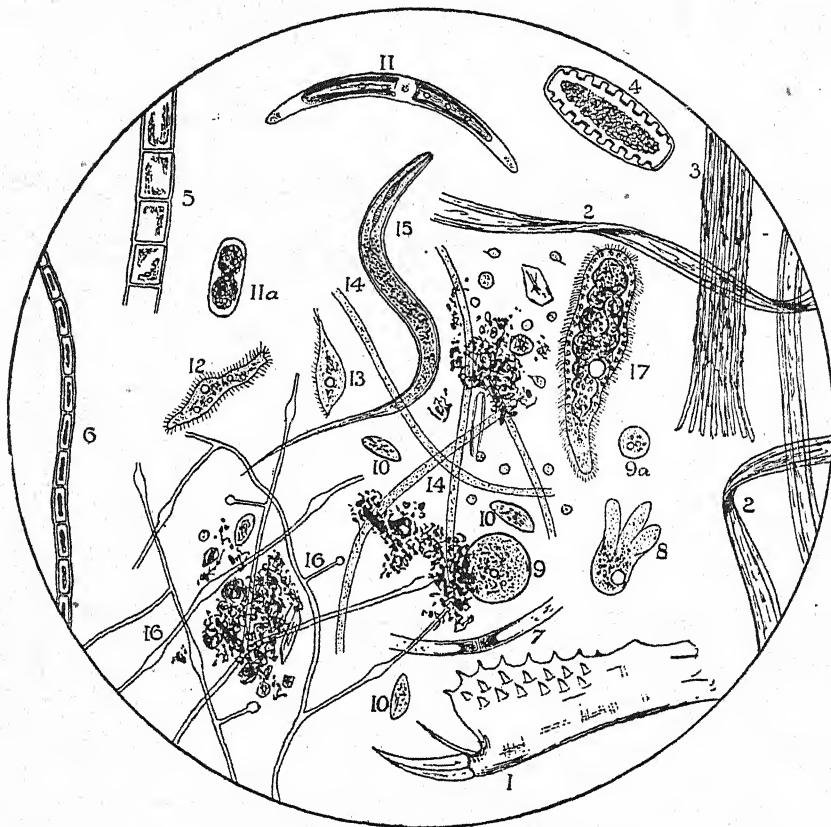


1 & 2. *Cyclops quadricornis*.
 2a and 3. Portions of carapace of same.
 4. Fungus in débris.

1 to 3 magnified about 50 diameters.
 4 magnified about 250 diameters.

PLATE XXIII

Water from a stream utilised as a public supply. Liable to pollution from farms, etc., above the intake.

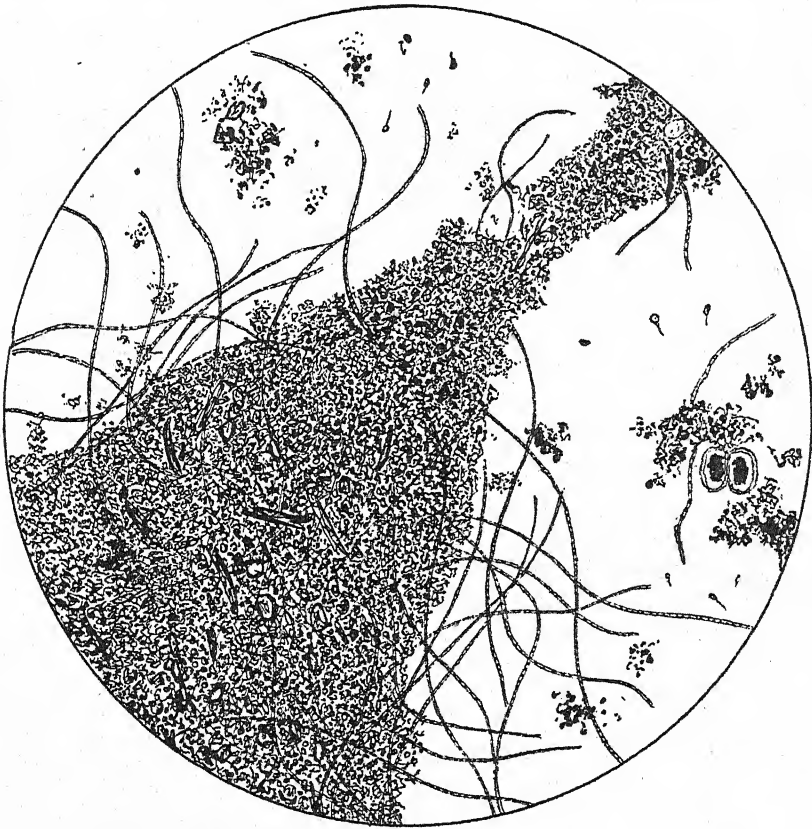


- | | |
|--|---|
| 1. Probably a mandible of some insect. | 11. Desmid. Closterium. |
| 2. Cotton, or cellulose threads. | 11a. Desmid. Penium. |
| 3. Probably a thread of hemp. | 12. An infusorian (?). |
| 4. Diatom. Surirella. | 13. Euplotes. An infusorian. |
| 5, 6 & 7. Algal threads, various species. | 14. Threads of a rather large Beggiatoa. |
| 8. Small amoeba. | 15. Anguillula. |
| 9 & 9a. Probably resting-stage of some infusorian. | 16. Fungus and debris. |
| 10. (?) | 17. A rather large infusorian, showing a very distinct vacuole. |

All magnified about 300 diameters.

PLATE XXIV

From a polluted water submitted for examination. Source not stated.

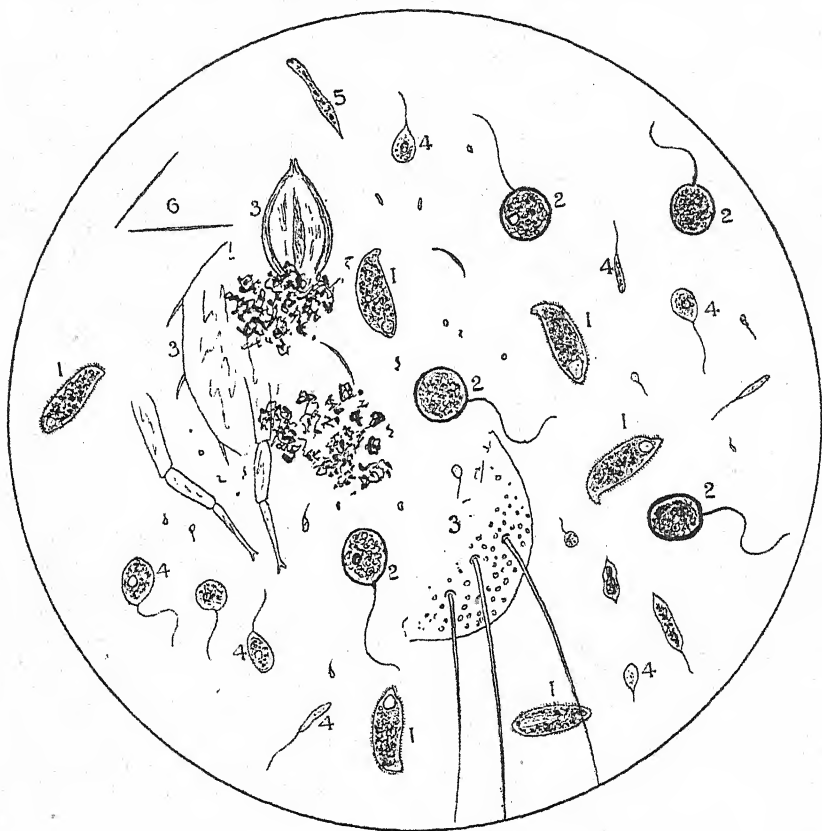


A mass of débris containing Beggiatoa.

Magnified about 300 diameters.

PLATE XXV

Growth in an open service reservoir. Water had been imperfectly filtered.



1. Ciliate infusorians.
- 2 & 4. Flagellate infusorians, various species.
3. Disorganised remains of minute animals.
5. Small form of *Euglena viridus*.
6. Crystals (?)

No. 3 magnified about 300 diameters.
Others magnified about 500 diameters.

PLATE XXVI

From an open well liable to pollution after rainfall.



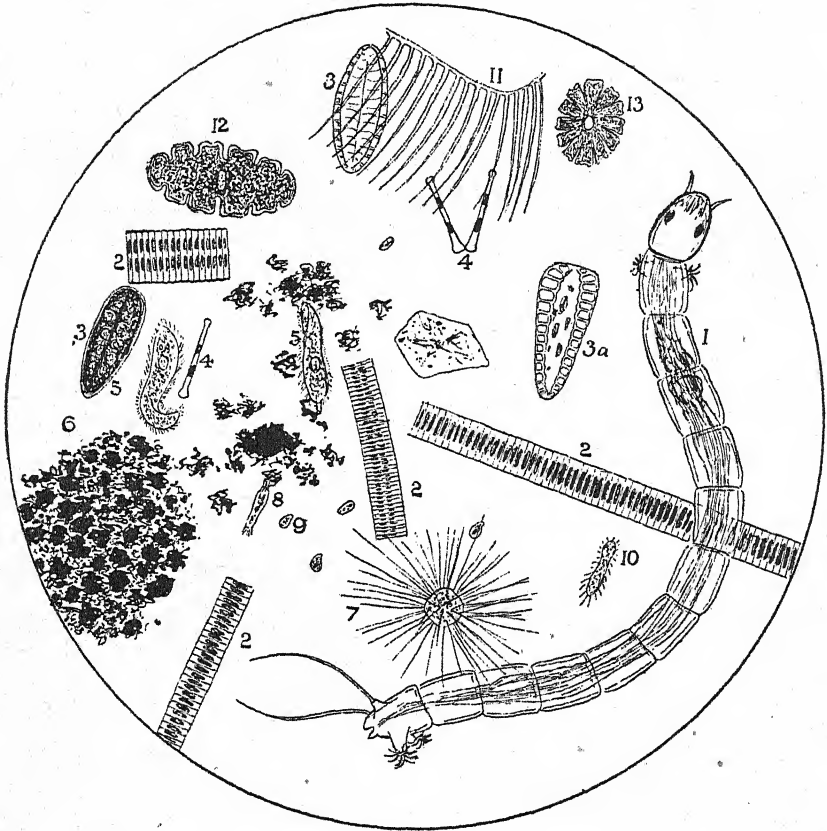
1. Portion of a cyclops.
2. Diatoms, various species.
- 3 & 3a. Oscillaria.
4. An algal thread.
5. A desmid (*Closterium*).
6. (?)

7. Minute infusorians.
8. Fungal hyphae.
9. Sand and debris.
10. Probably a fibre of hemp.
11. Cellulose fibres, probably cotton.
12. Zoogloea of bacteria.

All magnified about 300 diameters.

PLATE XXVII

From a large reservoir on the Derbyshire moors.

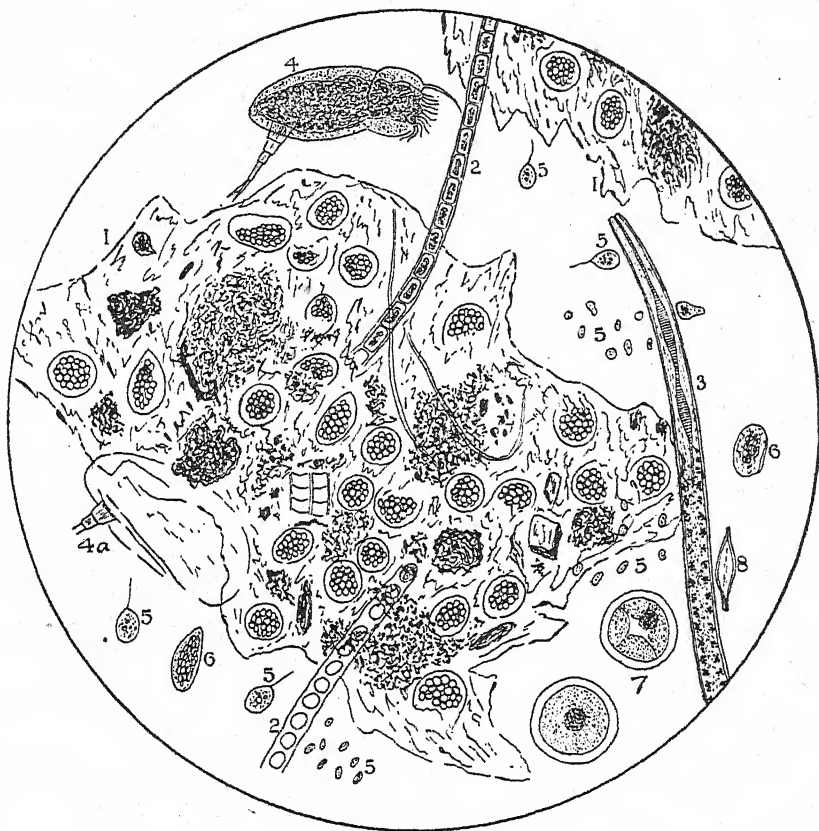


1. Larva of an insect fly.
2. Diatoms, *Fragilaria*.
- 3 & 3a. Diatoms, probably *Surirella*.
4. Diatoms, *Asterionella*.
5. Infusorians, species of paramoecia.
6. Case of mud inhabited by the larva (1).
7. *Actinophrys sol*.
- 8 & 9. Small infusorians.
10. Small infusorians with fewer and more rigid cilia.
11. Portions of a minute animal.
12. A desmid, *Euastrum*.
13. A desmid, *Pediastrum*.

1 & 6 magnified about 50 diameters.
Others magnified about 250 diameters.

PLATE XXVIII

From a house-tap. Moorland water alleged to have been filtered.

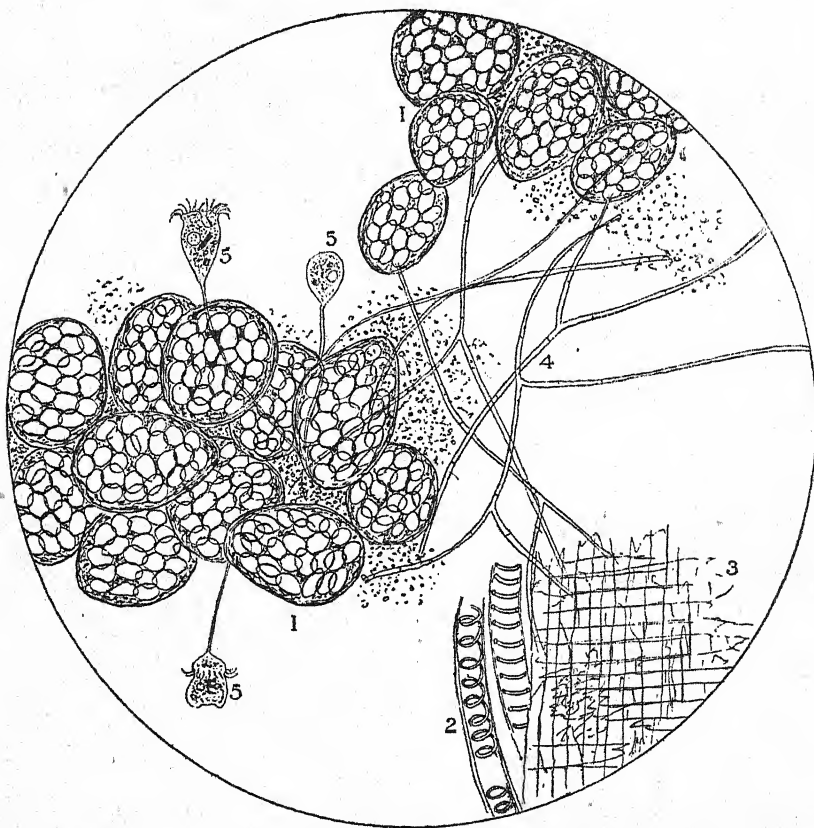


- | | |
|---|--|
| 1. Probably palmella, embedded in jelly, with which is associated animal and vegetable remains. | 4a. Disorganised remains of same. |
| 2. Algal threads. | 5. Minute flagellate infusorians. |
| 3. Portion of Anguillula. | 6. (?) |
| 4. A rotifer sp. | 7. Probably ova of some minute animal. |
| | 8. Diatom. |

4 & 4a magnified about 300 diameters.
Others magnified about 500 diameters.

PLATE XXIX

Shallow well. Public supply to a village.



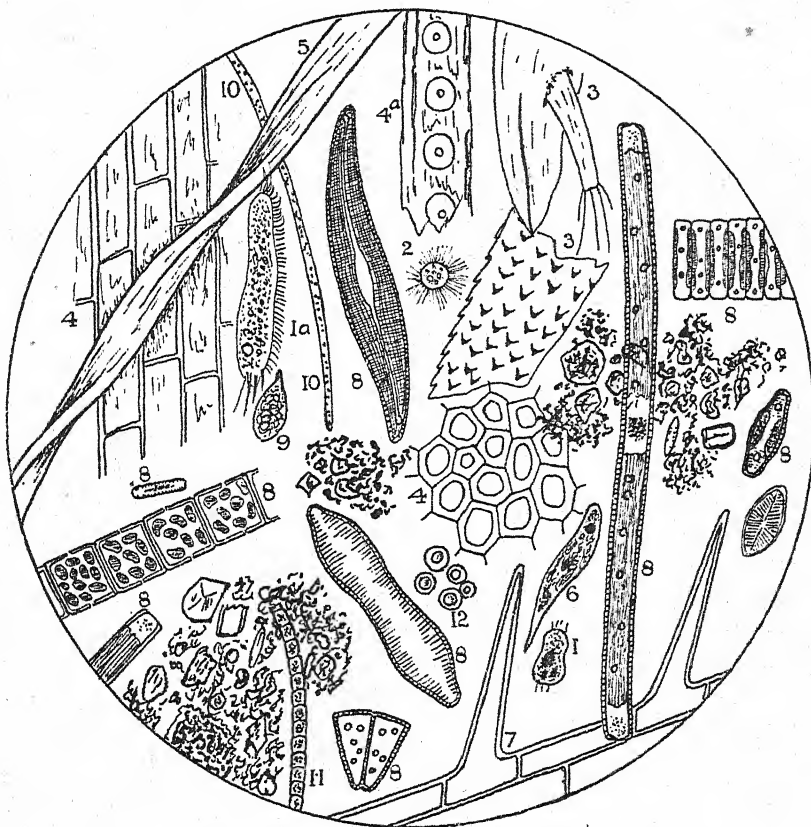
1. Vegetable cells, containing starch.
2 & 3. Vegetable fibres.

4. Fungal hyphae;
5. Vorticella.

All magnified about 200 diameters.

PLATE XXX

River water just above the intake of a waterworks.



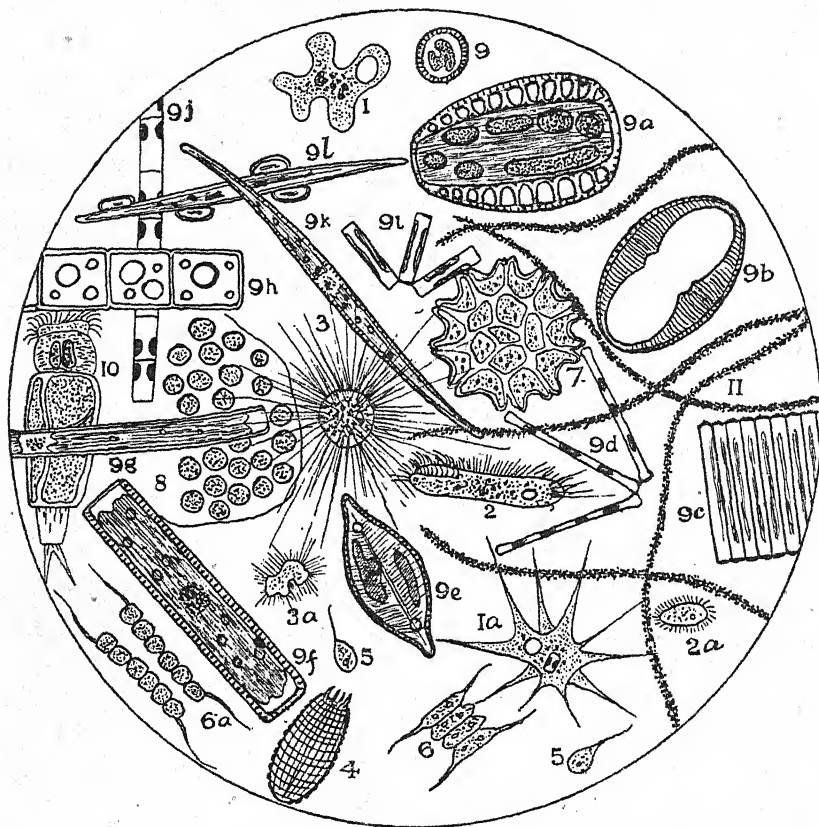
1. Small infusorian.
- 1a. Infusorian. Stylonychia.
2. Species of actinophrys.
3. Animal remains, probably portions of small crustaceans.
4. Vegetable debris.
- 4a. Coniferous wood-fibre.

5. Cellulose fibres.
6. *Euglena viridis*.
7. Vegetable hairs.
8. Various diatoms.
9. (?)
10. Thread of *Beggiatoa*.
11. Alga in debris.

Magnified about 400 diameters.

PLATE XXXI

Water from river connecting certain Norfolk Broads. (It is stored and filtered, and then used for a public supply.)

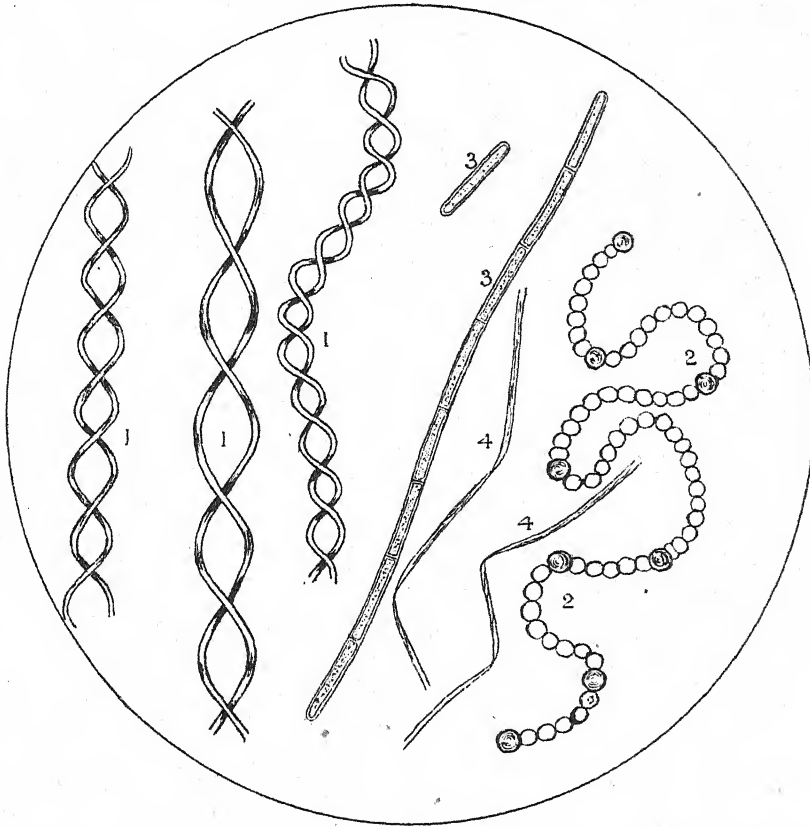


- | | |
|------------------------------------|--|
| 1. Amœba. | 6. A desmid. Scenedesmus. |
| 1a. An allied form. | 6a. An allied form. |
| 2. An infusorian. Stylonychia. | 7. A desmid. Pediastrum Boryanum. |
| 2a. Small infusorian. | 8. Palmella mucosa, embedded in jelly. |
| 3. A radiolarian. Actinophrys sol. | 9. a-l. Various diatoms. |
| 3a. An allied form. | 10. A rotifer, probably R. vulgaris. |
| 4. Coleps hirta. | 11. Fungal hyphæ with iron oxide. |
| 5. A monad, very active. | ? Cladotrix. |

No. 10 magnified about 100 diameters.
Others magnified about 250 diameters.

PLATE XXXII

Growth on exposed surface of chalk round fissures, from which water was issuing. The chalk was polluted with bisulphite liquor from a paper pulp works.

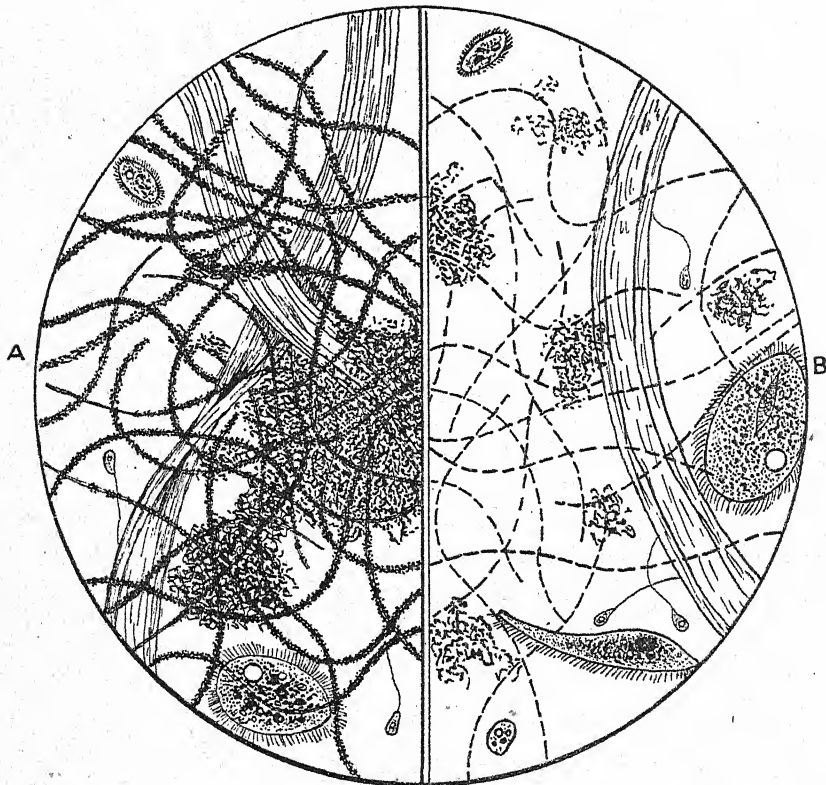


1. Predominating organism in sample. Apparently double spirilla, and probably one of the coloured, sulphur-bacteria.
2. Either a very small Nostoc or the sugar-bacterium (*Leuconostoc*) without gelatinous sheath (?).
3. Segmented, and
4. Unsegmented thread-bacilli.

All magnified 1,000 diameters.

PLATE XXXIII

Deposit formed in mains of a Water Authority. The water contained a trace of iron, under .05 per 100,000, and, when this was removed, the growth ceased. Water derived from wells in New Red Sandstone.



A. *Crenothrix*, with deposit of iron-oxide in and around the threads.

The deposit contained also a rather large quantity of vegetable fibre, and numbers of infusorians of the *Paramœcium* group.

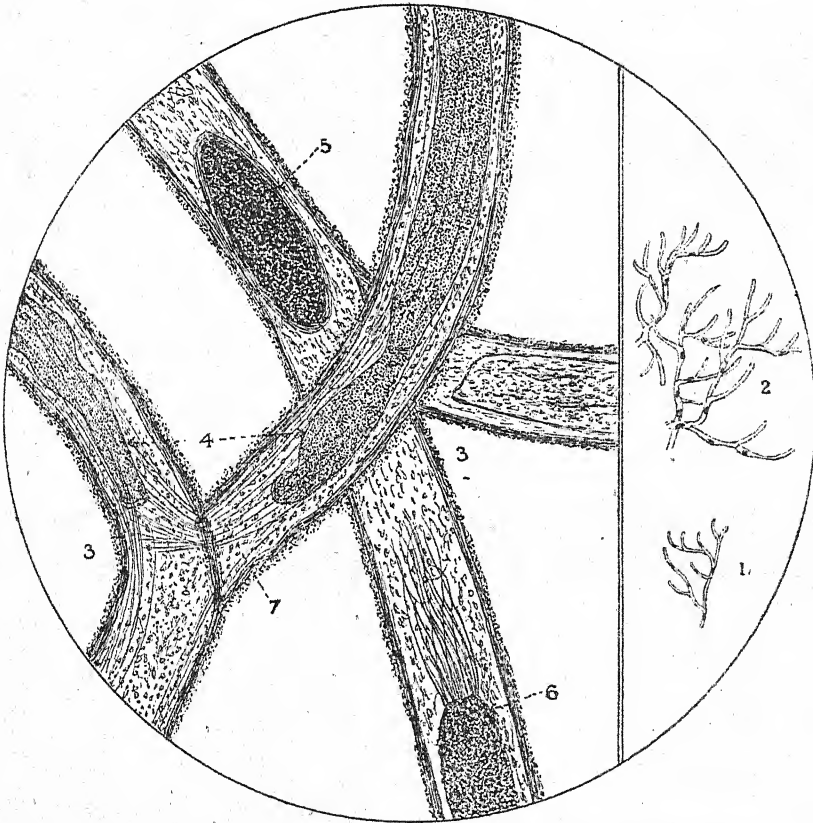
B. Shows the *Crenothrix* threads after treatment with acetic acid. The rods are enclosed in an invisible sheath.

Magnified 650 diameters.

PLATE XXXIV

Bryozoa

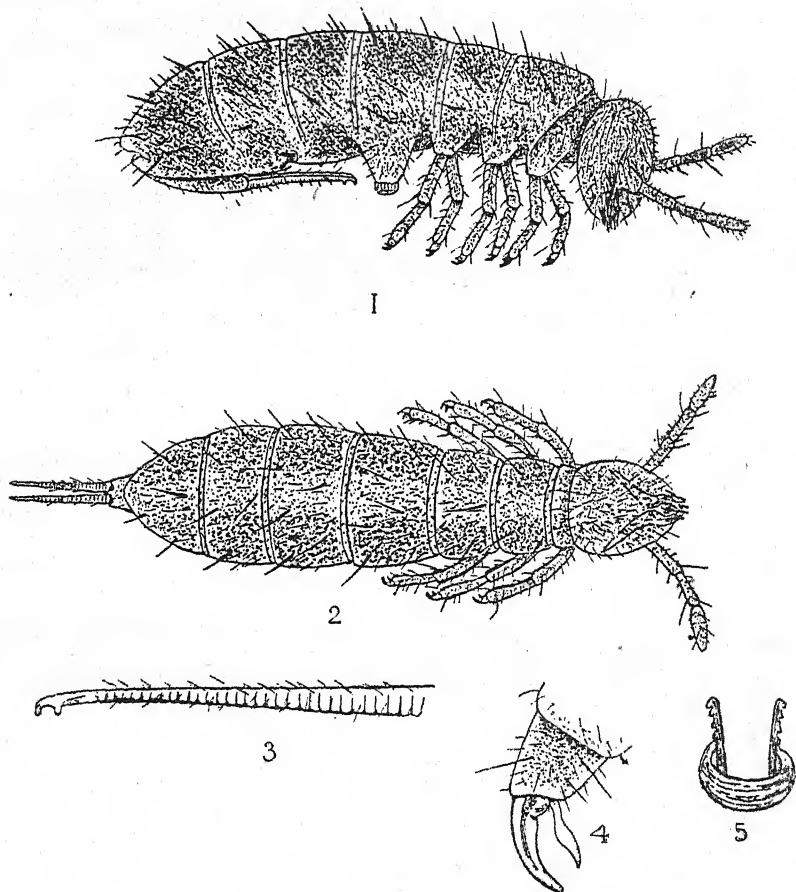
Growth found in the water mains of a town. How the mains became infected was not known, but it probably would not have occurred had the water (from moorlands) been efficiently filtered. Pieces of the growth became detached and passed through the taps, causing complaints. No tastes or odours were imparted to the water.



1. *Plumatella emarginata*, var., Muscosa detached growth. Natural size.
2. Same, slightly enlarged, to show branching and joints.
3. Portions of same, magnified about 30 times.
4. Animal contracted in sheath.
5. Statoblast, resting-stage.
6. Statoblast, apparently germinating and sending out tentacles.
7. Strongly marked striations.

PLATE XXXV

"Insects" which obtained access to the Edinburgh water mains through ball-hydrants.



1. *Isotoma aquatilis* of Lubbock, probably identical with *I. fimetaris* (Tulbb).
2. Same, surface view, "spring" extended.
3. Enlarged view of "spring," showing hooks and muscles.
4. Foot, showing two claws.
5. Enlarged view of the "catch," shown in fig. 1.

This organ is supposed to hold back, by means of its "cogs," the spring, which would be released by the drawing together of the two upright, horny portions of the "catch."

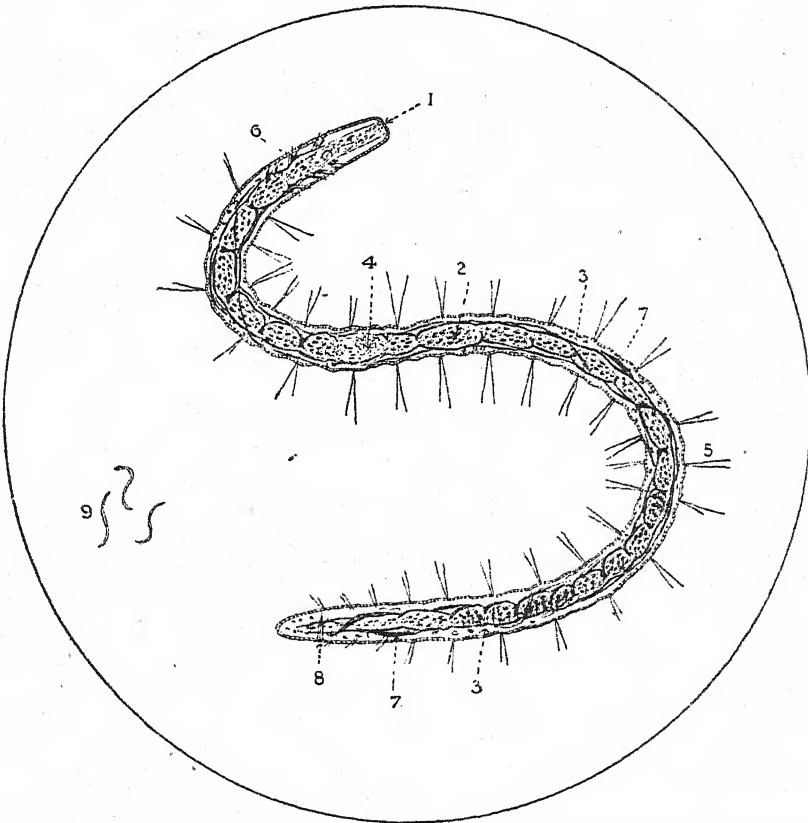
N.B.—"Sucker," shown in fig. 1, on first abdominal segment.

Magnified about 25 diameters.

PLATE XXXVI

The Nais, an Annelide Worm. N.O. Polychæta

Over a certain definite area of supply of a large Water Company complaints arose of the presence of worms in the water. Investigation limited the infection to one main and its branches. Ball-hydrants in use, and the boxes of many of these, were found to contain quantities of earthy matter. After these were cleansed, and the mains had been flushed, the worms disappeared.



- | | |
|--|---|
| 1. Mouth. | 5. Setae (rigid hairs), lying in any direction. |
| 2. Alimentary canal. | 6. Shorter hairs thickened near the middle. |
| 3. Body cavity, in which blood circulates. | 7. Excretory system. |
| 4. Probably reproductive portion. (Plainly marked in spring, and disappearing in summer and autumn.) | 8. Anus. |
| | 9. Nais, natural size. |

Magnified about 20 diameters.

APPENDIX

INDICATORS FOR DETERMINATION OF HYDROGEN ION CONCENTRATION

Indicator.	Range of pH.	Colour change
Cresol red (acid range)	0.2—1.8	Red—yellow.
<i>m</i> -Cresol purple (acid range)	0.5—2.5	Red—yellow.
Tropæolin OO	1.0—2.8	Red—yellow.
Thymol blue (acid range)	1.2—2.8	Red—yellow.
Bromo-phenol blue	2.8—4.6	Yellow—violet.
Congo red	3.0—5.0	Violet—red.
Methyl orange	3.1—4.4	Red—yellow.
Benzene-azo- <i>a</i> -naphthylamine	3.7—5.0	Red—orange.
Bromo-cresol green	3.6—5.2	Yellow—blue.
Methyl red	4.2—6.3	Red—yellow.
Chloro-phenol red	4.6—7.0	Yellow—red.
Propyl red	4.6—6.6	Red—yellow.
Litmus	5.0—8.0	Red—blue.
Bromo-cresol purple	5.2—6.8	Yellow—violet.
Bromo-thymol blue	6.0—7.6	Yellow—blue.
Neutral red	6.8—8.0	Red—orange.
Phenol red	6.8—8.4	Yellow—red.
Rosolic acid	6.9—8.0	Orange—red.
Cresol red (alkaline range)	7.2—8.8	Yellow—red.
<i>m</i> -Cresol purple (alkaline range)	7.6—9.2	Yellow—violet.
Thymol blue (alkaline range)	8.0—9.6	Yellow—blue.
<i>o</i> -Cresol-phthalein	8.2—9.8	Colourless—red.
Phenolphthalein	8.3—10.0	Colourless—red.
Thymol violet	9.0—13.0	Yellow—green—violet.
Alizarin blue S	9.0—11.0—13.0	Yellow—green—purple.
Thymol-phthalein	9.3—10.5	Colourless—blue.
Alizarin yellow G	10.1—12.0	Yellow—red.
Brilliant cresyl blue	10.5—12.5	Blue—brown.

The most useful for routine work with natural waters are bromo-thymol blue cresol red, methyl red and benzene-azo-*a*-naphthylamine or methyl orange.

For waters which have been treated with lime for softening or purification purposes, brilliant cresyl blue, thymol violet and thymol-phthalein are all useful.

In making media for bacteriological purposes bromo-thymol blue and phenol red are used.

PREPARATION OF INDICATOR SOLUTIONS

(1) **Stock Solutions.** Weigh out 0.1 gramme of the solid and grind in an agate mortar with the following amounts of N/20 sodium hydroxide and make up to 25 c.c. with distilled water :—

Indicator.	N/20 NaOH.
Bromo-phenol blue	3.0 c.c.
Bromo-thymol blue	3.2 „
Bromo-cresol purple	3.7 „
Thymol blue	4.3 „
Cresol red	5.3 „
Phenol red.	5.7 „

(2) **Test Solutions.** 1. Dilute 1 c.c. of above with 9 c.c. of distilled water, except with phenol red and cresol red, in which cases dilute 1 c.c. with 19 c.c. of water.

2. Methyl red. Dissolve 0.02 gramme in 60 c.c. of alcohol and add 40 c.c. of distilled water.

3. Phenolphthalein and benzene-azo-*a*-naphthylamine. Dissolve 0.04 gramme in 60 c.c. of alcohol and add 40 c.c. of distilled water.

PREPARATION OF REAGENTS AND MEDIA

Volumetric Solutions

(1) Solution of Sodium Carbonate (Decinormal).

Pure sodium carbonate, recently ignited and cooled	5.300 grammes
Distilled water	to 1 litre

Dissolve.

[1 c.c. = 5.3 mg. Na_2CO_3 = 4.8 mg. SO_4 = 3 mg. CO_3 .]

(2) Solution of Sulphuric Acid (Decinormal).

Strong pure sulphuric acid (sp. gr. 1.84)	2.7 c.c.
Distilled water	a sufficiency

Add the acid to 1 litre of water, and shake.

Take 20 c.c. of the decinormal solution of sodium carbonate in a beaker, dilute to 100 c.c. with distilled water, and add 1 or 2 drops of solution of methyl orange.¹ Run in the acid from a burette until the last drop produces a red colour, and note the amount used. Now add decinormal solution of sodium carbonate until the red colour disappears. Let a = the number of cubic centimetres of acid used, and b = the number of cubic centimetres of alkali required to remove the red colour:

then $a - \frac{b}{2}$ = the amount of acid required to neutralise exactly the 20 c.c. of sodium carbonate solution. Fifty times this quantity should then be taken and diluted with water to 1 litre.

Confirm the result by another similar experiment.

(3) Solution of Sulphuric Acid for Estimating Alkalinity as CaCO_3 .

Decinormal sulphuric acid	100 c.c.
Distilled water	400 "

Mix.

[1 c.c. = 1 mg. CaCO_3 .]

(4) Solution of Barium Chloride.

Pure crystals barium chloride (dried by exposure over strong sulphuric acid in a desiccator for a few hours)	5.084 grammes
Distilled water	1 litre

Dissolve.

[1 c.c. = 2 mg. SO_4 .]

(5) Solution of Potassium Chromate.

Pure crystals of potassium chromate (dried by exposure in an oven at 120° C.)	4.05 grammes
Distilled water	1 litre

Dissolve.

[This solution is equivalent in strength to the barium chloride solution.]

¹ or Benzene-azo-*a*-naphthylamine.

(6) Solution of Silver Nitrate.

Crushed crystals of pure silver nitrate (dried in an air oven at 105° C.)	4.791 grammes
Distilled water	1 litre

Dissolve.

[1 c.c. = 1 mg. chlorine in chlorides.]

(7) Solution of Potassium Nitrate.

Powdered crystals of potassium nitrate (dried in an oven at about 110° C.)	7.221 grammes
Distilled water	1 litre

Dissolve.

[1 c.c. = 1 mg. N.]

(8) Solution of Sodium Nitrite.

Pure silver nitrite	1.1 grammes
Sodium chloride	0.5 gramme
Distilled water	a sufficiency

Dissolve the silver nitrite in about half a litre of the water by aid of heat. Add the sodium chloride and, when cold, dilute to 1 litre. Allow to stand in the dark, and decant the supernatant clear fluid. Keep in a dark place.

[1 c.c. = 0.1 mg. N.]

(9) Solution of Sodium Phosphate.

Pure sodium phosphate ($\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$)	0.377 gramme
Distilled water	100 c.c.

Dissolve.

[1 c.c. = 1 mg. PO_4 .] *Vide* also (31).**(10) Solution of Iodine.**

Freshly sublimed iodine	1.269 grammes
Pure potassium iodide	2 grammes (about)
Distilled water	to 100 c.c.

Dissolve the potassium iodide in a minimum quantity of water and add the iodine. Allow the iodine to dissolve and then make up to 100 c.c. This forms a decinormal solution. For use in estimating H_2S in water it can be diluted with 9 volumes of water to form the centinormal solution.

(11) Solution of Ammonium Chloride.

Fine crystals of pure ammonium chloride (dried in an oven at 105° C.)	3.14 grammes
Distilled water	1 litre

Dissolve.

[1 c.c. = 1 mg. NH_3 .]**(12) Dilute Solution of Ammonium Chloride.**

Solution of ammonium chloride	10 c.c.
Distilled water	990 „

Mix.

[1 c.c. = 0.01 mg. NH_3 .]

(13) Solution of Sodium Thiosulphate, $\frac{N}{10}$.

Sodium thiosulphate	.	.	.	.	.	25 grammes
Sodium bicarbonate	.	.	.	.	.	5 "
Distilled water	.	.	.	.	.	to 1 litre

Dissolve. Standardise against $\frac{N}{10}$ iodine solution (10).

(14) Dilute Solution of Thiosulphate, $\frac{N}{80}$.

Solution of thiosulphate, $\frac{N}{10}$	.	..	.	.	10 c.c.
Distilled water	.	.	.	.	70 "

Mix.

[1 c.c. = 0.1 mg. oxygen.]

To be made as required and standardised before use against No. (16)

(15) Solution of Potassium Permanganate, $\frac{N}{8}$.

Crystals of potassium permanganate (dried at 100° C. in a platinum or glass dish in an air oven)	.	.	.	.	.	3.950 grammes
Distilled water	.	.	.	.	.	1 litre

Dissolve.

[1 c.c. = 1.37 mg. Mn = 1 mg. available oxygen.]

(16) Dilute Solution of Potassium Permanganate, $\frac{N}{80}$.

Solution of potassium permanganate	.	.	10 c.c.
Distilled water	.	.	90 "

Mix.

The strong solution, stored in an amber bottle in a dark place, keeps very well. The dilute solution should be freshly prepared every few days.

The solution of potassium permanganate may be standardised with ferrous ammonium sulphate; 49.02 parts of this salt require 1 part of oxygen for the conversion of ferrous into ferric sulphate. An accurately known quantity (about half a gramme) of the pure crystals is dissolved in about 100 c.c. of freshly boiled distilled water, 5 c.c. of dilute sulphuric acid (No. 51) added, and the permanganate added until the last drop produces a faint but distinct pink tint. If the permanganate solution is not absolutely accurate in strength, the factor obtained from the test should be marked on the label.

(17) Solution of Calcium Chloride.

Powdered calc-spar which has been dried by heating in the air oven to 120° C. for about half an hour	.	.	.	.	.	1 gramme
Hydrochloric acid	.	.	.	.	.	a sufficiency
Distilled water	.	.	.	.	.	to 1 litre

Place the calc-spar in a shallow beaker, add about 50 c.c. of the water, and heat on the water-bath. Add a little hydrochloric acid from time to time until the spar is dissolved. To avoid loss by spurting, cover the beaker with a watch-glass. When solution has taken place, rinse the watch-glass with a little distilled water and evaporate to dryness. Add a few cubic centimetres of water and again evaporate. Repeat this a third time. Finally, dissolve the residue in 1 litre of freshly-boiled distilled water.

[1 c.c. contains calcium equivalent to 1 mg. of CaCO_3 .]

(18) Solution of Soap.

Sapo mollis, B.P.	50 grammes
Methylated spirit free from petroleum	} equal parts a sufficiency
Distilled water	

Dissolve the soap in 1 litre of the mixture of spirit and water. Set aside in a very cool place (preferably in a refrigerator) for twenty-four hours. Filter. Standardise the solution in the following way:—

Take 10 c.c. of the calcium chloride solution and dilute with 90 c.c. of distilled water in a bottle capable of holding about 200 c.c. Add the soap solution drop by drop, shaking thoroughly after each addition, until a permanent lather is produced. Note the amount required, and dilute 100 a to 1100 c.c.

a = number of cubic centimetres of the soap solution used.

Repeat the standardisation by adding the soap solution in 1 c.c. quantities, and finally in drops, to 10 c.c. of the calcium chloride diluted as previously. If the soap solution used for producing a lather is not exactly 11 c.c., add more dilute spirit or stronger soap solution until, upon shaking, a final experiment shows that the soap solution is of the required strength. The lather should be such as that which is produced by adding 1 c.c. of the soap solution to 100 c.c. of freshly boiled and cooled distilled water. It should persist when the bottle is laid on its side for five minutes.

Exposure of the soap solution to low temperatures should be avoided, but, should this occur and the soap precipitate, it may be redissolved by standing the bottle containing the solution in tepid water.

If, upon keeping, the solution becomes turbid, the standardisation must be repeated. As the strength may be found to be slightly reduced, the excess of strong soap solution should be preserved for bringing the solution again to the required strength.

Alternative Method for the Determination of Total Hardness

If supplies of soap of suitable quality for the preparation of standard soap solution are unavailable, as may be the case in war-time, the following alternative method can be employed for the determination of total hardness.

Solutions required:

N/50 sulphuric acid.

Alkali solution consisting of equal parts of N/50 sodium hydroxide and N/50 sodium carbonate.

Method. A known volume of the water, sufficient to contain 10 to 20 mg. of hardness as CaCO_3 , is placed in a beaker and accurately neutralised with the N/50 acid, a preliminary test having been separately

made, using methyl orange as indicator, to ascertain the exact amount of acid required. The water is then boiled to expel carbon dioxide, after which 50 c.c. of the alkali solution are added. Boiling is resumed until the volume is small, and the evaporation continued by standing the beaker on a hot-plate or water-bath until the residue is almost dry, *i.e.*, still contains a little moisture. The precipitated calcium carbonate and magnesium hydroxide are then washed from the beaker with freshly boiled, hot, distilled water on to a filter paper and the washing continued to completion. The filtrate is carefully collected and titrated with the N/50 acid, using methyl orange as indicator.

Example. If 100 c.c. of the water are taken and 30 c.c. of the acid are required in the final titration, the hardness of the water is $50 - 30 = 20$ parts per 100,000.

This method gives results which are usually slightly lower than, but within 5 per cent. of, the total hardness calculated as CaCO_3 from the determinations of the calcium and magnesium contents of the water.

(19) Solution of Ferric Chloride.

Pure iron wire	0.1 gramme
Dilute hydrochloric acid	5 c.c.

Dissolve by aid of heat in a small flask, then add

Potassium chlorate	0.25 gramme
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and boil until free from the odour of chlorine. Dilute with distilled water to 1 litre.

[1 c.c. = 0.1 mg. Fe.]

(20) Solution of Lead Acetate.

Pure lead acetate crystals	0.183 gramme
Acetic acid	a sufficiency
Distilled water	1 litre

Dissolve the lead acetate in about 100 c.c. of water, add sufficient acetic acid to render the solution distinctly acid; then dilute to 1 litre.

[1 c.c. = 0.1 mg. Pb.]

(21) Acetic Acid Solution for Lead Test.

Acetic acid, B.P.	100 c.c.
Gelatin	0.5 gramme

Dissolve in the cold.

(22) Solution of Zinc Sulphate.

Pure zinc sulphate	0.440 gramme
Distilled water	1 litre

Dissolve.

[1 c.c. = 0.1 mg. Zn.]

(23) Solution of Magnesium Chloride.

Pure magnesium wire	0.250 gramme
Dilute hydrochloric acid	20 c.c.
Distilled water	to 1 litre

Dissolve the magnesium in the acid in a large flask, and dilute with water to 1 litre.

[1 c.c. = 0.25 mg. Mg.]

Reagents for Estimation of Dissolved Oxygen

(24) Solution of Sodium Nitrite and Potassium Iodide.

Sodium nitrite	. . . . .	0.5 gramme
Potassium iodide	. . . . .	20 grammes
Solution of sodium hydroxide	. . . . .	1 c.c.
Distilled water	. . . . .	100 „

Dissolve.

(25) Solution of Sodium Thiosulphate.

Pure dry crystals of sodium thiosulphate	. . . . .	7.76 grammes
Distilled water	. . . . .	to 1 litre

Dissolve.

[1 c.c. = 0.25 mg. of oxygen.]

(26) Solution of Manganous Sulphate.

Manganous sulphate	. . . . .	50 grammes
Distilled water	. . . . .	100 c.c.

Dissolve.

(27) Alkaline Solution of Potassium Iodide.

Potassium iodide	. . . . .	10 grammes
Purified potassium hydroxide	. . . . .	70 „

Dissolve and make up to 100 c.c.

(27A) Alkaline Tartrate for Miller's Method.

Crystallised Rochelle salt	. . . . .	180 grammes
Sodium hydroxide	. . . . .	70 „

Dissolve the Rochelle salt in 300 c.c. of hot distilled water, filter and add the sodium hydroxide. Cool and make up to 500 c.c.

Reagents for Estimation of Dissolved Carbon Dioxide

(28) Solution of Barium Hydroxide.

Barium hydroxide crystals	. . . . .	10 grammes
Barium chloride	. . . . .	0.2 gramme
Distilled water	. . . . .	1 litre

Dissolve and filter. This solution must be standardised immediately before use.

(29) Solution of Barium Chloride.

Barium chloride crystals	. . . . .	10 grammes
Distilled water	. . . . .	100 c.c.

Dissolve and filter.

Reagents for Estimation of Phosphates

(30) Denigès' " Cerulo-molybdic " Solution, as Modified by Florentin.

Solution (a).

Ammonium molybdate	. . . . .	10 grammes
Distilled water	. . . . .	to 100 c.c.

Dissolve. Then add

Strong sulphuric acid	. . . . .	150 c.c.
Distilled water	. . . . .	150 „

mix and cool.

Solution (b). Dissolve

Pure tin	. . . . .	0.1 gramme in
Hydrochloric acid	. . . . .	2 c.c.

Add

Three per cent. solution copper sulphate	. . . . .	0.1 c.c. and
Distilled water	. . . . .	to 10 c.c.

This solution must be freshly prepared.

(31) Sodium Ammonium Hydrogen Phosphate Solution.

Sodium ammonium hydrogen phosphate ($\text{NaNH}_4\text{HPO}_4 \cdot 4\text{H}_2\text{O}$)	. . . . .	1.473 grammes
Distilled water	. . . . .	to 100 c.c.
[1 c.c. = 5 mg. P_2O_5 .]		

(32) Kastle-Meyer's Reagent for Detecting Copper.

Phenolphthalein	. . . . .	2 grammes
Potassium hydroxide	. . . . .	20 „
Distilled water	. . . . .	100 c.c.

Dissolve; add 10 grammes zinc-dust and boil until the colour is discharged, allow to stand, and decant.

(33) Solution of Copper Sulphate.

Copper sulphate, pure, cryst.	. . . . .	0.393 gramme
Distilled water	. . . . .	1 litre
[1 c.c. = 0.1 mg. Cu.]		

(34) For determination of tar acids in water the following solutions are required :—

1. Recrystallised sulphanilic acid, 1.910 grammes in 250 c.c. distilled water.
 2. Pure sodium nitrite, 0.850 gramme in 250 c.c. distilled water.
 3. Dilute sulphuric acid, 1 part (sp. gr. 1.84) to 3 parts of water.
 4. Eight per cent. solution of sodium hydroxide.
 5. One per cent. solution of mixed cresols in water.
- The mixed cresols should contain 35 per cent. ortho-, 40 per cent. meta-, and 25 per cent. para-cresol.

(35) Solutions for Determination of Silica.

1. Ten per cent. solution of ammonium molybdate in distilled water.
2. Dilute sulphuric acid 1 in 4.
3. For estimation of colour produced :—

Picric acid, pure, vacuum dried	. . . . .	0.0256 gramme
Distilled water	. . . . .	100 c.c.

(35A) A.P.H.A. Method for Silica in Boiler Waters.

This method is applicable to boiler waters which contain phosphates.

1. Sodium hydroxide-borate buffer solution. Solution A, 12.40 grammes of boric acid plus 100 ml. of 1 N sodium hydroxide per litre.

Solution B, N/10 sodium hydroxide. The buffer solution is made by taking 6 parts of solution A and 4 parts of solution B. This solution has a pH of 10. The buffer is kept in a hard rubber bottle.

2. Calcium chloride solution. 2 N calcium chloride.

3. Ammonium molybdate solution. Ten per cent. solution of $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 4\text{H}_2\text{O}$.

4. Hydrochloric acid. Three volumes of concentrated acid to 2 volumes of distilled water.

Calcium chloride, ammonium molybdate, and hydrochloric acid are kept in Pyrex glass bottles.

(36) Colour Determination.

Bismarck brown solution (strong).

Bismarck brown	1 gramme
Fifty per cent. alcohol	1 litre

For use

Strong solution	25 c.c.
Fifty per cent. alcohol	1 litre
[1 c.c. added to 1 litre distilled water = 1 unit of colour.]	

Platinum Cobalt Standard, A.P.H.A. Dissolve 0.5 gramme of platinum in *aqua regia*; remove nitric acid by repeated evaporation to dryness after adding an excess of hydrochloric acid. Dissolve this product with 1 gramme of crystals of cobalt chloride in 100 c.c. of distilled water and 100 c.c. of strong hydrochloric acid and dilute with water to 1 litre.

This solution has a colour of 500.

Burgess's Solution. Cobalt sulphate 1 gramme, potassium dichromate 0.05 gramme, distilled water 1 litre.

(37) Turbidimetric Measurements.

Powdered dry fuller's earth g.s.

Sift gently through a piece of very fine muslin and weigh out 1 gramme. Diffuse this through 1 litre of distilled water. Dilute 10 c.c. to 100 c.c. with distilled water and pour into the turbidimeter and note distance at which needle is barely discernible. If the mixture is correct, the reading will be 10 cm.

FORMULÆ FOR REAGENTS

(38) Solution of Ammonium Carbonate.

Ammonium carbonate	5 grammes
Solution of ammonia (sp. gr. 0.89)	5 c.c.
Distilled water	95 "

Dissolve and filter.

(39) Solution of Ammonium Molybdate.

1. Ammonium molybdate	10 grammes
Distilled water	30 c.c.
Solution of ammonia (sp. gr. 0.89)	10 "

Dissolve.

2. Nitric acid (sp. gr. 1.42)	60 c.c.
Distilled water	60 "

Mix, and pour into the molybdate solution with constant stirring. Allow to stand for several days, and decant the clear solution.

(40) **Solution of Ammonium Phosphate.**

Ammonium phosphate $[(\text{NH}_4)_2\text{HPO}_4]$	10 grammes
Distilled water	100 c.c.

Dissolve, and add solution of ammonia (sp. gr. 0.89) until a permanent turbidity is produced. Filter.

(41) **Solution of Ammonium Oxalate.**

Ammonium oxalate	4 grammes
Distilled water	100 c.c.

Dissolve. Filter if necessary.

(42) **Acid Solution of Barium Chloride.**

Barium chloride	10 grammes
Hydrochloric acid	20 c.c.
Distilled water	80 "

Dissolve the chloride in the water, and add the acid.

(43) **Solution of Calcium Hydroxide.**

Pure calcium hydroxide	3 grammes
Distilled water	100 c.c.

Shake together at frequent intervals for a few hours, then allow to stand, and pour away the supernatant liquid. Repeat this operation. Finally add 250 c.c. distilled water to the residue; shake at intervals for twenty-four hours. Allow to settle, and draw off the lime-water as required. The bottle can be refilled with distilled water many times.

(44) **Solution of Copper Sulphate.**

Copper sulphate	3 grammes
Distilled water	100 c.c.

Dissolve and filter.

(45) **Dilute Hydrochloric Acid.**

Hydrochloric acid (sp. gr. 1.16)	40 c.c.
Distilled water	200 "

Mix.

(46) **Ilosvay's Solution.**

1. Sulphanilic acid	0.5 gramme
Glacial acetic acid	30 c.c.
Distilled water	120 "

Dissolve.

2. Naphthylamine	0.1 gramme
Glacial acetic acid	30 c.c.
Distilled water	120 "

Dissolve the naphthylamine in the acetic acid, add the water. Grind the sulphanilic acid in a mortar with a little acetic acid. Wash the mixture into a beaker with the remaining acetic acid, heat to 60°-70° C. for five minutes and pour it into the water.

(47) Solution of Potassium Chromate.

Potassium chromate	10 grammes
Distilled water	100 c.c.

Add a few drops of volumetric solution of silver nitrate until a permanent red precipitate is produced. Filter.

(48) Alkaline Solution of Potassium Permanganate.

1. Potassium permanganate	8 grammes
Distilled water	1 litre

Dissolve by the aid of heat.

2. Potassium or sodium hydroxide	200 grammes
Distilled water	500 c.c.

Mix 1 and 2, and boil until volume is reduced to 1,000 c.c.

An enamelled iron kettle answers well for this purpose. During the evaporation the lid is left off. When the flame is removed the cover is replaced, and finally, when cool, the solution can be easily poured into the stock bottle. The kettle should be used for no other purpose.

(49) Solution of Platinic Chloride.

Platinum foil	10 grammes
Hydrochloric acid (sp. gr. 1.16)	60 c.c.
Nitric acid (sp. gr. 1.42)	10 „
Distilled water to produce	200 „

Warm the hydrochloric acid to 80° C., add the platinum, pour in the nitric acid very gradually, and evaporate the solution to dryness on the water-bath. Moisten the residue with a few drops of hydrochloric acid; again evaporate to dryness. Finally, dissolve the residue in sufficient water to make 200 c.c. of the solution.

(50) Alkaline Solution of Mercuric Iodide (Nessler's Solution).

1. Prepare a cold saturated solution of mercuric chloride.
2. Dissolve 35 grammes of potassium iodide in 100 c.c. of distilled water. Pour 1 into 2 until, after thorough agitation, a slight red precipitate remains permanent.

Now add 120 grammes of sodium or potassium hydroxide and, when dissolved, dilute to 1 litre. Finally add a little more of the mercuric chloride solution to produce a red colour. Set aside to clear.

The delicacy of the reagent appears to be increased by keeping for a few weeks before use, and it should be shaken up occasionally.

(51) Dilute Sulphuric Acid.

Sulphuric acid, (sp. gr. 1.843)	100 c.c.
Distilled water	300 „

Pour the acid gradually into the water with constant stirring. Allow to get quite cold, and drop in volumetric solution of potassium permanganate until the faint pink tint persists for four hours.

(52) Solution of Sodium Hydroxide (free from Ammonia, Nitrites and Nitrates).

Sodium hydroxide prepared from sodium	10 grammes
Distilled water	110 c.c.

Dissolve, and boil until the volume is reduced to 100 c.c.

(53) Solution of Starch.

Potato starch	.	.	.	.	.	.	4 grammes
Zinc chloride.	.	.	.	.	.	.	20 "
Water	.	.	.	.	.	.	1 litre

Dissolve the zinc chloride in about 100 c.c. of water, and filter. Mix the starch with a few cubic centimetres of cold water into a thin paste and pour into the boiling solution of zinc chloride with constant stirring. Dilute to 1 litre. Allow the flocculent matter to settle and filter the supernatant fluid through a small jelly-bag.

(54) King's Fluid for Preserving Algæ, etc.

Copper chloride	.	.	.	.	.	.	0.20 gramme
Copper nitrate	.	.	.	.	.	.	0.20 "
Glacial acetic acid	.	.	.	.	.	.	0.5 c.c.
Camphor water	.	.	.	.	.	.	100 "

Make a solution, and filter.

(55) Test Solution for Free Chlorine.

Ortho-tolidine	.	.	.	.	.	.	1 gramme
Hydrochloric acid (sp. gr. 1.18)	.	.	.	.	.	.	100 c.c.

Grind the *o*-tolidine in a mortar with a little of the acid. Titurate the paste with further successive quantities of the acid, and finally make up to 1 litre with distilled water.

MEDIA FOR BACTERIOLOGICAL WORK

Care should be exercised in the selection of ingredients, as certain varieties are liable to show considerable variation in quality, reaction, etc. After many years' search for standardised products capable of yielding uniform results, we found the materials supplied by the Difco Laboratories Inc., Detroit, to be most satisfactory, and, in cases where only small quantities of media are required, the dehydrated media prepared by this firm are to be recommended. The agar, peptone, meat extract, etc., used in the following formulæ are Difco "Bacto" products except where otherwise stated. On the other hand, the Standard Lactose (bacteriologically tested) supplied by Messrs. British Drug Houses is guaranteed to withstand autoclaving and is eminently suitable for all media incorporating this sugar. Peptones of good quality, such as Peptone (Evans) and Eupeptone (Allen and Hanbury), are available.

The ingredients are dissolved in distilled water, usually by the aid of heat. The reaction is then tested and adjusted if necessary. For this purpose a small quantity of the medium is cooled and 10 c.c. transferred to a comparator where it is titrated using N/20 sodium hydroxide with phenol red as indicator. The requisite amount of N/1 sodium hydroxide is then slowly added to the bulk medium with constant agitation. The medium is then boiled for ten minutes and any turbidity removed by filtration. Media containing agar or gelatin must, of course, be filtered while hot, and in such cases it is essential to use either a paper pulp bed or a Chardin filter paper. For other media the ordinary Whatman No. 40 filter paper serves equally well. The reaction of the filtrate should be checked and, if necessary, readjusted. The requisite quantities of the clear medium are then distributed into test

tubes which are thereafter plugged with cotton-wool and sterilised. In most cases sterilisation is effected by autoclaving at 120° C. (pressure of one atmosphere) for twenty minutes.

Instead of plugged test tubes it is often preferable to use screw-capped bottles such as are obtainable from Messrs. United Glass Bottle Manufacturers Ltd. These are particularly suitable for media which are not in daily use, for medium contained therein keeps sterile almost indefinitely and does not evaporate. The glass of these bottles usually contains some free alkali which must be removed before use. For this purpose it is advisable to fill the bottles with distilled water, autoclave and test the reaction. The process of filling and autoclaving must be repeated until the distilled water remains neutral to phenol red. Similar precautions are also necessary with most glassware.

(56) Nutrient (Extract) Broth.

Difco meat extract	.	.	.	.	.	3 grammes
(or Lab. Lemco meat extract)	.	.	.	.	.	5 "
Sodium chloride	.	.	.	.	.	5 "
Peptone	.	.	.	.	.	10 "
Distilled water	.	.	.	.	.	1,000 c.c.

Dissolve in 800 c.c. of hot distilled water and bring to the boil. Cool, dilute to 1 litre and adjust the reaction to pH 7.5. Boil for ten minutes, filter and cool. Distribute in 5 c.c. volumes and autoclave.

Purpose. For liquid culture of most organisms, and for incorporation in other media.

(57) Nutrient (Infusion) Broth (after Wright, *J. Path. Bact.*, 37, 257, 1933).

Peptone	.	.	.	.	.	10 grammes
Sodium chloride	.	.	.	.	.	5 "
Meat (preferably veal), finely minced after	.	.	.	.	.
removal of excess fat	.	.	.	.	.	500 "
Distilled water	.	.	.	.	.	to 1,000 c.c.

Add the ingredients to the distilled water in the order indicated. Mix well and heat for twenty minutes at 68° C., stirring at intervals. Shake well, and steam in the steam steriliser for thirty minutes, filter, and adjust the reaction to pH 7.8. Again steam for thirty minutes and filter. Check the reaction of the filtrate (pH 7.6). Distribute as required in already autoclaved receptacles and sterilise by steaming for thirty minutes on three successive days.

Purpose. For liquid culture of delicate organisms, and for incorporation in other media.

(58) Nutrient Agar.

Powdered (or washed, shredded) agar	.	.	.	.	15 grammes
Nutrient broth (extract or infusion)	.	.	.	.	1,000 c.c.

Dissolve by heat, cool to 50° C., adjust the reaction to pH 7.2, steam for ten minutes, distribute as required (usually 10 c.c. volumes) and autoclave. If shredded agar has been used, it is necessary to filter before distribution.

Purpose. For the preparation of "agar slopes." After autoclaving, the tubes are allowed to cool in a sloping position.

(59) Yeastrel Agar.

Yeastrel (Brewers' Food Supply Co. Ltd.)	3 grammes
Peptone	5 "
Powdered (or washed, shredded) agar	15 "
Distilled water	1,000 c.c.

Add the ingredients to cold distilled water, dissolve by steaming for thirty minutes, and adjust the reaction at 50° C. to pH 7.2. Filter while hot through a Chardin filter paper (preferably in the steamer), tube in 10 c.c. quantities and autoclave.

Purpose. For enumeration of bacteria in water.

(60) Nutrient Gelatin.

To 1 litre of nutrient (extract) broth add 120 grammes (in winter) or 160 grammes (in summer) of best sheet gelatin. Dissolve on a water-bath, cool to 50° C., and adjust the reaction to pH 7.5. Add the whites of two eggs, mix thoroughly, heat for thirty minutes at 100° C., filter in the steamer. Distribute 10 c.c. quantities in already autoclaved screw-capped bottles and sterilise by steaming for twenty minutes on three successive days.

Purpose. For testing the liquefying properties of organisms.

(61) Bile-salt Lactose Peptone Litmus Solution (MacConkey Lactose Broth).

Formula for "double-strength" medium :

Sodium taurocholate	10 grammes
Lactose (B.D.H. Standard)	20 "
Peptone	40 "
Sodium chloride	10 "
Distilled water	1,000 c.c.

Dissolve by bringing to the boil, cool to room temperature and adjust the reaction to pH 7.4. Bring to the boil and filter while hot. Store in ice-chest overnight. If the medium becomes cloudy refilter cold. Add sufficient strong aqueous solution of litmus (dissolved by steaming, filtered and then autoclaved) to give a decided purple colour when the medium is diluted with its own volume of water. Neutral red may be used instead of litmus, in which case about 4 c.c. of a 1 per cent. aqueous solution are required. Make the volume up to 1 litre.

For 50 c.c. of water. Distribute 50 c.c. of the broth in 100 c.c. flasks or 4 oz. screw-capped bottles each containing an inverted (Durham) tube (3 inches by $\frac{1}{4}$ inch).

For 10 c.c. of water. Distribute 10 c.c. quantities in test tubes (6 inches by $\frac{3}{4}$ inch) or 1 oz. screw-capped bottles each containing an inverted (Durham) tube (2 inches by $\frac{1}{4}$ inch).

For 1 c.c. or less of water. Mix equal volumes of the broth and distilled water and distribute 5 c.c. volumes of the dilution into test tubes (5 inches by $\frac{5}{8}$ inch) each containing a Durham tube (2 inches by $\frac{1}{4}$ inch).

Sterilise all by autoclaving at 10 lb. for 15 minutes.

Purpose. For the presumptive coliform reaction.

(62) Neutral-red Bile-salt Lactose Agar (MacConkey Agar).

Sodium taurocholate	.	.	.	.	.	5 grammes
Peptone	.	.	.	.	.	20 "
Sodium chloride	.	.	.	.	.	5 "
Powdered agar	.	.	.	.	.	20 "
Distilled water	.	.	.	.	.	1,000 c.c.

Steam till solids are dissolved. Cool to 50° C. Adjust the reaction to pH 7·6 to 7·8. Steam for thirty minutes. Filter while hot. Cool the filtrate to 50° C. and adjust the reaction to pH 7·3. Now add :

Lactose (B.D.H. Standard)	.	.	.	.	10 grammes
Neutral red 1 per cent. aqueous solution (approx.)	.	.	.	.	5 c.c.—10 c.c.

Distribute in 15 c.c. quantities and autoclave at a pressure of 10 lb. for fifteen minutes.

Purpose. For "coliform" counts and in the differentiation of coliform and other intestinal bacteria.

(63) Endo Agar.**A. Stock agar medium :**

Lab. Lemco meat extract	.	.	.	.	5 grammes
Peptone	.	.	.	.	10 "
Agar	.	.	.	.	30 "
Distilled water	.	.	.	.	1,000 c.c.

Boil until solids are dissolved. Cool and adjust the reaction to pH 7·5. Add the white of an egg, mix, steam for one to two hours and filter while hot through a Chardin filter paper. Distribute in 100 c.c. volumes and autoclave.

B. Basic fuchsin solution :

Basic fuchsin (Gurr)	3 grammes
Alcohol 95 per cent.	.	.	.	.	100 c.c.

Allow to stand for twenty-four hours, decant and filter.

Medium for use :

Stock agar medium (A)	.	.	.	.	100 c.c.
Lactose	.	.	.	.	1 gramme
Stock fuchsin solution (B)	.	.	.	.	1 c.c.
Anhydrous sodium sulphite (freshly dissolved in 5 c.c. of distilled water)	.	.	.	.	0·125 gramme

Distribute in 15 c.c. quantities and sterilise by steaming for twenty minutes on three successive days. Store in the dark.

Purpose. For differentiation of coliform and other intestinal bacteria.

(64) Eosin Methylene-blue Agar.**Stock agar medium :**

Peptone	.	.	.	.	10 grammes
Dipotassium hydrogen phosphate (K_2HPO_4)	.	.	.	.	2 "
Agar	.	.	.	.	15 "
Distilled water	.	.	.	.	1,000 c.c.

Boil until solids are dissolved. Make up volume to 1 litre. Distribute in 100 c.c. quantities and autoclave.

Medium for use :

Stock agar medium	100 c.c.
Lactose, 20 per cent. aqueous solution (sterile)	5 "
Eosin yellow, 2 per cent. aqueous solution	2 "
Methylene blue, 0.5 per cent. aqueous solution	2 "

Distribute in sterile Petri dishes. (Filtration and adjustment of reaction are not required.)

Purpose. For differentiation of coliform and other intestinal bacteria.

(65) Peptone Water.

Peptone	10 grammes
Sodium chloride	5 "
Distilled water	1,000 c.c.

Dissolve by heat; adjust reaction to pH 7.5. Boil and filter if necessary. Distribute in 5 c.c. quantities and autoclave.

Purpose. For indole reaction. Results may be more quickly obtained if Bacto-tryptone is used instead of peptone in the above formula.

(66) Erlich's Reagent.

Paradimethylaminobenzaldehyde	1 gramme
Concentrated hydrochloric acid	20 c.c.
Absolute alcohol	100 "

The above is the standard Erlich's reagent which has always been applied to the indole test in the past. The following modification gives greatly improved results :—

Paradimethylaminobenzaldehyde	5 grammes
Amyl alcohol (pyridine-free)	75 c.c.
Concentrated hydrochloric acid	25 "

This reagent when prepared should have a yellow colour.

Purpose. For indole test.

(67) Glucose Phosphate Medium.

Peptone	5 grammes
Dipotassium hydrogen phosphate (K_2HPO_4) *	5 "
Glucose	5 "
Distilled water	1,000 c.c.

Dissolve by gentle warmth. Adjust the reaction (if necessary) to pH 7.8. Heat and filter if necessary. Distribute 5 c.c. quantities in tubes and sterilise by steaming at 100° C. for twenty minutes on three successive days.

Purpose. For methyl red and Voges-Proskauer tests.

(68) Methyl Red Indicator Solution.

Methyl red	0.1 gramme
Alcohol	300 c.c.
Distilled water	to 500 "

* This should be alkaline to phenolphthalein.

(69) Citrate Medium.

Sodium chloride	5.0 grammes
Magnesium sulphate	0.2 „
Ammonium dihydrogen phosphate ($\text{NH}_4\text{H}_2\text{PO}_4$)	1.0 „
Dipotassium hydrogen phosphate (K_2HPO_4)	1.0 „
Citric acid	2.0 „
Distilled water	1,000 c.c.

Adjust the reaction to *pH* 6.8. Distribute in 5 c.c. quantities and autoclave at a pressure of 15 lbs. for ten minutes.

Purpose. For the differentiation of coliform bacteria.

(70) Uric Acid Medium.

Sodium chloride	5.0 grammes
Magnesium sulphate	0.2 „
Calcium chloride	0.1 „
Dipotassium hydrogen phosphate (K_2HPO_4)	1.0 „
Glycerol	30.1 „
Uric acid	0.5 „
Distilled water (ammonia free)	1,000 c.c.

Distribute 5 c.c. quantities and autoclave.

Purpose. For differentiation of coliform bacteria.

(71) Litmus Milk.

Fill a separating funnel with fresh milk (free from any preservative) and place in the steam steriliser for thirty minutes. Then allow to stand in the refrigerator for twenty-four hours. Draw off the separated milk and adjust the reaction to *pH* 7.5. Now add 10 per cent. litmus solution until the milk attains a purplish colour. Distribute 5 c.c. quantities and sterilise by steaming for thirty minutes on three successive days.

Purpose. For differentiation of intestinal bacteria.

(72) Sugar Media.

Peptone water (of <i>pH</i> 7.5) containing sufficient litmus solution and autoclaved	100 c.c.
Ten per cent. solution of the required sugar (sterilised by steaming for thirty minutes)	5 „

With aseptic precautions distribute 5 c.c. quantities into sterile test tubes containing sterile Durham tubes, and sterilise by steaming for twenty minutes on three successive days.

Purpose. For bacterial fermentation tests.

(73) Glucose Sulphite Iron Agar (Wilson and Blair).

Nutrient agar (3 per cent. agar) melted	100 c.c.
Twenty per cent. solution of anhydrous sodium sulphite	10 „
Twenty per cent. solution of glucose	5 „
Eight per cent. solution of ferrous sulphate crystals	1 „

Purpose. For isolation of *Cl. welchii*.

(74) Milk Medium (for Anaerobic Spores).

Preparation described on p. 513.

(75) Fletcher's Medium.

Rabbit serum	12 c.c.
Distilled water	to 100 „
Heat to 50° C. and add.	
Nutrient agar (2.5 per cent. agar)	6 „

Adjust the reaction to pH 7.4 and sterilise by heating to 56° C. for one hour on two successive days.

Purpose. Cultivation of leptospiræ.

(76) Bismuth Sulphite Agar.

Stock mixture :

	Wilson & Blair.	Tabet's Modification.
Bismuth ammonio-citrate scales	6 grammes	6 grammes
Sodium sulphite, anhydrous	20 „	10 „
Sodium phosphate, anhydrous	10 „	3.5 „
Glucose	10 „	10 „
Distilled water	200 c.c.	200 c.c.

The bismuth scales and the sulphite are dissolved in 50 c.c. and 100 c.c. respectively of boiling distilled water and the two solutions are mixed. The phosphate is added to the mixture while still at the boil, and the glucose (previously dissolved in 50 c.c. of distilled water) is added to the bulk when cool. No sterilisation is required.

Medium for use :

Hot melted nutrient agar (2 per cent. agar)	100 c.c.
Stock mixture	20 „
Ferrous sulphate, 8 per cent. aqueous solution	1 „
Brilliant green, 1 per cent. aqueous solution	0.5 c.c.

Mix and pour into sterile Petri dishes.

Purpose. Isolation of enteric organisms.

Note. The dehydrated Difco "Bismuth Sulfite Agar" medium is recommended as giving uniform results and saving much time and trouble.

(77) Brilliant Green Eosin Agar (Jones).

Hot, melted, sterile nutrient agar (made up with beef infusion and Difco proteose peptone)	20.0 c.c.
Lactose, 20 per cent. solution (sterile)	1.0 „
Eosin (water-soluble), 5 per cent. aqueous solution.	0.6 „
Brilliant green, 0.1 per cent. aqueous solution	0.2 to 1.0 „

The requisite amount of brilliant green to be added is first determined by a preliminary standardisation experiment using pure cultures of *Bact. typhosum* and *Bact. coli*.

The medium, after shaking, is poured into sterile Petri dishes and allowed to set. The plates are dried by incubating overnight at 37° C.

Purpose. Selective cultivation of enteric organisms.

Tetrathionate Broth.**(78) A. Kauffmann's Medium.**

Meat infusion broth	90 c.c.
Calcium carbonate (pre-sterilised by autoclaving)	5 grammes
Sodium thiosulphate crystals, 50 per cent. solution (pre-sterilised by steaming)	10 c.c.
Unheated solution of iodine and potassium iodide (20 gm. I_2 + 25 gm. KI + distilled water to 100 c.c.)	2 "
Brilliant green, 0.1 per cent. aqueous solution	1 "
Sterile ox-bile	5 "

With continuous shaking to keep the chalk evenly distributed, pour 5 c.c. quantities of the medium into already autoclaved test tubes or bottles. No sterilisation is necessary and no heat should be applied as the tetrathionate is liable to become decomposed.

Purpose. For selective cultivation of enteric organisms.

(79) B. Szper's Medium.

Concentrated meat extract (1 kgm. meat per 400 c.c. of water)	100 c.c.
Sodium chloride	2 grammes
Peptone	5 "
Bile, three times concentrated by evaporation	8 c.c.
Calcium carbonate (pre-sterilised by autoclaving)	22.5 grammes

Sterilise the mixture by steaming for thirty minutes. Now add :

Sodium thiosulphate crystals, 50 per cent. solution (sterile)	40 c.c.
Solution of iodine and potassium iodide (20 gm. I_2 + 25 gm. KI + distilled water, 100 c.c.)	8 "
Brilliant green, 1 per cent. aqueous solution	4 "

The completed medium lasts for only three days. To 200 c.c. of the medium are added 1,000 c.c. of the water to be examined.

Purpose. Isolation of enteric organisms from water.

(80) C. Modification of Kauffmann's Medium for Water.

- Five times concentrated nutrient infusion broth (already autoclaved) 300 c.c.
- Calcium carbonate (already autoclaved) 75 grammes

The mixture is steamed for thirty minutes.

- Sodium thiosulphate crystals ($Na_2S_2O_3 \cdot 5H_2O$). 75 "
- Distilled water to 125 c.c.

Sterilise by steaming for thirty minutes in a 200 c.c. flask.

- Iodine 6 grammes
- Potassium iodide 7.5 "
- Distilled water to 30 c.c.

First dissolve the potassium iodide in a few cubic centimetres of distilled water, then add the iodine which should go into solution quite readily. Now make the volume up to 30 c.c. with distilled water.

- Bacto ox-gall, 15 per cent. aqueous solution 50 c.c.
- Brilliant green, 0.1 per cent. aqueous solution 15 "

All the above are kept ready in the proportions and amounts indicated. When it is desired to examine a litre of water for enteric

organisms, the whole sample is added to the concentrated broth. The iodine solution (3) is then added to the thiosulphate (2), mixed and immediately transferred to the bulk. (It is essential that no time is lost in this operation as the concentrated thiosulphate becomes cloudy within two minutes owing to deposition of sulphur). The ox-gall and brilliant green solutions are then added, being mixed in at each addition.

Purpose. Isolation of enteric organisms from water.

(81) **Desoxycholate-citrate Agar.** (Leifson. *J. Path. Bact.*, **40**, 581, 1935.)

The final medium has the following composition :—

Agar (B.D.H.)	22.5 grammes
Lab. Lemco	5 "
Difco proteose peptone	5 "
Lactose	10 "
Neutral red	0.025 gramme
Sodium citrate	8 grammes
Sodium thiosulphate	8 "
Ferric citrate	1 gramme
Sodium desoxycholate	5 grammes
Water	to 1 litre

1. Agar Base.

Dissolve 20 grammes Lab. Lemco in 200 c.c. water over the flame ; make just alkaline to phenolphthalein with 50 per cent. NaOH ; boil and filter. Adjust the pH to 7.3 ; make up the volume to 200 c.c. and add 20 grammes Difco Proteose Peptone.

Dissolve 90 grammes agar in 3,700 c.c. distilled water, by one hour's steaming.

Filter the agar ; add the Lab-Lemco-peptone solution, and mix.

Add 5 c.c. 2 per cent. neutral red and 40 grammes lactose. Mix.

Bottle in accurate 100 c.c. lots and sterilise by free steam (and up to 5 lbs.) for one hour.

2. Solution A.

Sodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7 \cdot 2\text{H}_2\text{O}$)	16 grammes
Sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$)	16 "
Ferric citrate (scales)	2 "
Distilled water	100 c.c.

Dissolve by heat or by standing at room temperature for two days.

3. Solution B.

Sodium desoxycholate	10 grammes
Distilled water	100 c.c.

These solutions need not be sterilised.

For use, melt 100 c.c. of the agar base, and add 5 c.c. each of solutions A and B in this order, using separate pipettes and mixing well between. Pour plates and dry the surface.

Purpose. For the cultivation of dysentery bacteria.

(82) **Alkaline Blood Agar** (Dieudonné).

Defibrinated ox-blood	15 c.c.
Sodium hydroxide normal (<i>i.e.</i> , 4 per cent.) solution	15 "

Steam the mixture for thirty minutes ; add to :

Melted sterile nutrient agar (3 per cent. agar)	70 "
---	------

Pour into sterile Petri dishes and allow these to stand at room temperature for a day or two.

Purpose. Selective cultivation of *Vibrio cholerae*.

(83) **Ringer's Solution.** (Full strength)

Sodium chloride	9.00 grammes
Potassium chloride	0.42 "
Calcium chloride	0.48 "
Sodium bicarbonate	0.20 "
Distilled water	1 litre

Diluted solution for use :

Full strength solution	250 c.c.
Distilled water	to 1 litre

The distilled water must be pure, free from copper and other bactericidal agents, and the diluted solution should be sterilised by autoclaving at 15 lbs. for twenty minutes.

Purpose. As a diluent.

(84) **Gram's Method of Staining** (as suggested by the Medical Research Committee in "Reports of the Special Committee upon the Standardisation of Pathological Methods" (Special Report Series, No. 19), published by H.M. Stationery Office).

Jensen's Method. 1. Make the film thin and evenly distributed.

2. Fix by passing through a flame (guard against overheating by testing the heated slide against the back of the hand).

3. Let the preparation become cool.

4. Stain with a 0.5 per cent. aqueous solution of methyl violet for one-quarter to half a minute.

5. Pour off the mass of methyl violet solution and wash away the remainder with a drop or two of strong Lugol's solution. (To make this, add to 1 gramme of iodine and 2 grammes of potassium iodide 2 c.c. of distilled water, mix and dissolve; then make up the volume to 100 c.c. with distilled water).

6. Pour on a fresh quantity of strong Lugol's solution and leave for one-half to one minute.

7. Wash off the iodine solution with absolute alcohol (98 per cent.).

8. Pour on fresh absolute alcohol, moving the slide from side to side as in developing a photographic film. A third quantum of absolute alcohol may be required to complete decolorisation.

9. Finally, rinse with a few drops of absolute alcohol followed immediately by a solution of neutral red made in the proportion of :—

Neutral red	1 gramme
Distilled water	1 litre
1 per cent. glacial acetic acid	2 c.c.

Let this act for one minute.

10. Wash in water, dry with clean filter paper and in air. Mount and examine.

Note. Water is not used on the slide until the final wash. To check the technique, it is recommended that a film of a known Gram-positive organism and of a known Gram-negative organism be placed at the end of the slide and stained with the organism to be examined.

TABLE OF ATOMIC WEIGHTS

Name.	Symbol.	Approximate.	International (1941).
Aluminium	Al	27	26.97
Antimony	Sb	122	121.76
Arsenic	As	75	74.91
Barium	Ba	137	137.36
Bismuth	Bi	209	209.00
Boron	B	11	10.82
Bromine	Br	80	79.916
Cadmium	Cd	112	112.41
Calcium	Ca	40	40.08
Carbon	C	12	12.010
Chlorine	Cl	35.5	35.457
Chromium	Cr	52	52.01
Cobalt	Co	59	58.94
Copper	Cu	63.5	63.57
Fluorine	F	19	19.00
Hydrogen	H	1	1.008
Iodine	I	127	126.92
Iron	Fe	56	55.85
Lead	Pb	207	207.22
Lithium	Li	7	6.940
Magnesium	Mg	24	24.32
Manganese	Mn	55	54.93
Mercury	Hg	201	200.61
Nickel	Ni	59	58.69
Nitrogen	N	14	14.008
Oxygen	O	16	16.0000
Phosphorus	P	31	30.98
Platinum	Pt	195	195.23
Potassium	K	39	39.096
Selenium	Se	79	78.96
Silicon	Si	28	28.06
Silver	Ag	108	107.880
Sodium	Na	23	22.997
Sulphur	S	32	32.06
Tin	Sn	119	118.70
Zinc	Zn	65	65.38

MOLECULAR WEIGHTS OF VARIOUS SALTS

Salt.	Formulae of salt used in making reagents.	Molecular weights usually employed.
Sodium carbonate	Na_2CO_3	106.0
Barium chloride	$\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$	244.3
Potassium chromate	K_2CrO_4	194.2
Silver nitrate	AgNO_3	169.9
Potassium nitrate	KNO_3	101.1
Silver nitrite	AgNO_2	153.9
Sodium phosphate	$\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$	358.2
Ammonium chloride	NH_4Cl	53.5
Sodium thiosulphate	$\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$	248.2
Potassium permanganate	KMnO_4	158.0
Lead acetate	$(\text{CH}_3\text{COO})_2\text{Pb} \cdot 3\text{H}_2\text{O}$	379.2
Zinc sulphate	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	287.6

OXYGEN DISSOLVED BY DISTILLED WATER WHEN SATURATED WITH AIR AT DIFFERENT TEMPERATURES

(ROSCOE AND LUNT)

Temperature ° C.	c.c. oxygen at N.P.T.	Mg. of oxygen per litre of water.
5	8.68	12.3
6	8.49	12.05
7	8.31	11.80
8	8.13	11.55
9	7.95	11.29
10	7.77	11.03
11	7.60	10.79
12	7.44	10.56
13	7.28	10.34
14	7.12	10.11
15	6.96	9.88
16	6.82	9.68
17	6.68	9.48
18	6.54	9.28
19	6.40	9.08
20	6.28	8.92

WEIGHT OF 1 C.C. OF VARIOUS GASES AT N.P.T.

Air	1.293 mg.
Hydrogen	0.090 "
Oxygen	1.429 "
Nitrogen	1.251 "
Hydrogen sulphide	1.529 "
Carbon dioxide	1.977 "
Chlorine	3.214 "
Sulphur dioxide	2.927 "
Ammonia	0.771 "

ESTIMATION OF IONS

Factors for Use in Calculating the Results of Analyses

Ca	×	1.50	=	CO ₃	CO ₃	×	0.667	=	Ca
Mg	×	2.47	=	CO ₃	CO ₃	×	0.404	=	Mg
Na	×	1.31	=	CO ₃	CO ₃	×	0.765	=	Na
K	×	0.769	=	CO ₃	CO ₃	×	1.30	=	K
Ca	×	2.40	=	SO ₄	SO ₄	×	0.417	=	Ca
Mg	×	3.95	=	SO ₄	SO ₄	×	0.253	=	Mg
Na	×	2.09	=	SO ₄	SO ₄	×	0.479	=	Na
K	×	1.23	=	SO ₄	SO ₄	×	0.814	=	K
Ca	×	1.77	=	Cl	Cl	×	0.565	=	Ca
Mg	×	2.92	=	Cl	Cl	×	0.343	=	Mg
Na	×	1.54	=	Cl	Cl	×	0.649	=	Na
K	×	0.907	=	Cl	Cl	×	1.10	=	K
Ca	×	3.09	=	NO ₃	NO ₃	×	0.323	=	Ca
Mg	×	5.10	=	NO ₃	NO ₃	×	0.196	=	Mg
Na	×	2.70	=	NO ₃	NO ₃	×	0.371	=	Na
K	×	1.59	=	NO ₃	NO ₃	×	0.631	=	K

Cl × 0.368 = K in K₂PtCl₆

Cl × 0.701 = KCl in K₂PtCl₆

The amount of any ion in the first column multiplied by the factor in the second column gives the amount of the ion in the third column with which it will combine.

SPECIFIC GRAVITIES TABLES

Sodium Chloride

Specific gravity $\frac{20^{\circ}}{4^{\circ}}$ C.	Percentage of sodium chloride weight/weight.	Grammes of sodium chloride per litre.
1.0053	1	10.05
1.0125	2	20.25
1.0268	4	41.07
1.0413	6	62.48
1.0559	8	84.47
1.0707	10	107.1
1.0857	12	130.3
1.1009	14	154.1
1.1162	16	178.6
1.1319	18	203.7
1.1478	20	229.6
1.1640	22	256.1
1.1804	24	283.3
1.1972	26	311.3

Sodium and Potassium Hydroxides¹

Specific gravity $\frac{15^{\circ}}{4^{\circ}}$ C.	Grammes of sodium hydroxide per 100 c.c.	Grammes of potassium hydroxide per 100 c.c.
1.634	—	94.0
1.615	—	90.2
1.530	—	75.6
1.438	57.5	—
1.397	50.6	54.3
1.370	46.2	50.6
1.332	40.0	45.1
1.190	20.0	25.5

Ammonia¹

Specific gravity $\frac{15^{\circ}}{4^{\circ}}$ C.	Grammes of ammonia per 100 c.c.	Specific gravity $\frac{15^{\circ}}{4^{\circ}}$ C.	Grammes of ammonia per 100 c.c.
.880	31.0	.896	26.6
.882	30.83	.898	26.05
.884	30.14	.900	25.5
.886	29.46	.902	24.94
.888	28.86	.906	23.83
.890	28.26	.910	22.74
.892	27.70	.920	20.01
.894	27.15	.926	18.42

Sulphuric Acid ¹

Specific gravity 15° 4° C.	Grammes of sulphuric acid per 100 c.c.	Specific gravity 15° 4° C.	Grammes of sulphuric acid per 100 c.c.
1.840	175.9	1.552	100.0
1.838	173.9	1.542	98.1
1.835	171.7	1.520	93.6
1.833	170.4	1.492	88.95
1.830	168.5	1.420	74.0
1.825	166.1	1.380	66.2
1.815	161.8	1.295	50.0
1.800	156.4	1.200	32.8

Hydrochloric Acid ¹

Specific gravity 15° 4° C.	Grammes of hydrochloric acid per 100 c.c.	Specific gravity 15° 4° C.	Grammes of hydrochloric acid per 100 c.c.
1.160	36.6	1.133	30
1.155	35.3	1.113	25
1.152	34.5	1.091	20
1.150	34.0	1.056	12
1.145	32.8	1.047	10
1.140	31.5	1.0375	8

¹ From Cole's "Practical Physiological Chemistry."SOLUBILITY OF VARIOUS SALTS IN WATER AT 16° C.
IN PARTS PER 100, after Bunsen (see p. 305)

BaSO ₄	0.005	SrCl ₂	40.0
SrSO ₄	0.018	LiNO ₃	40.4
CaSO ₄	0.205	CaCl ₂	40.6
Ba(NO ₃) ₂	7.6	LiCl	43.1
NaHCO ₃	8.6	NH ₄ Br	44.7
K ₂ SO ₄	9.4	NaBr	46.1
Na ₂ SO ₄	11.9	SrBr ₂	49.9
KHCO ₃	18.3	Mg(NO ₃) ₂	50.0
KNO ₃	21.1	BaBr ₂	50.6
Na ₂ CO ₃	22.0	Ca(NO ₃) ₂	53.3
KCl	25.0	NH ₄ NO ₃	55.0
BaCl ₂	25.8	CaBr ₂	58.0
NH ₄ Cl	26.3	KI	58.1
NH ₄ I	31.4	MgI ₂	59.8
(NH ₄) ₂ SO ₄	33.0	LiI	61.1
MgSO ₄	33.7	LiBr	62.3
NaNO ₃	34.0	NaI	63.0
Li ₂ SO ₄	34.5	SrI ₂	63.6
Sr(NO ₃) ₂	34.8	BaI ₂	66.5
NaCl	35.9	MgCl ₂	66.6
MgBr ₂	36.0	CaI ₂	66.7
KBr	38.0	K ₂ CO ₃	100.0

For Tables of Solubilities, the reader is referred to "The Chemists' Year Book" compiled by Atack and Hope.

SAND FILTRATION

Filtering Sand (British Specification) :—

Sand layer	.	.	.	.	2 feet thick.
All the sand passes a	.	.	.	.	$\frac{3}{16}$ -inch circular hole.
70 per cent.	„	.	.	.	$\frac{3}{32}$ -inch square hole.
10 „ „	„	.	.	.	$\frac{1}{10}$ -inch „ „

Slow Sand Filtration

Filtering Speeds

Vertical feet. In 24 hours.	Inches per hour.	Gallons per square yard per day.	Gallons per acre per day.
2	1	112.50	544,500
4	2	225.00	1,089,000
6	3	337.50	1,633,500
8	4	450.00	2,178,000
10	5	562.50	2,722,500
12	6	675.00	3,267,000
14	7	787.75	3,811,500
16	8	900.00	4,356,000
18	9	1012.50	4,900,500
20	10	1125.00	5,445,000

1 inch per hour = 2 cubic feet per square foot per day
 = 12.5 gallons per square foot per day
 = 544,500 gallons per acre per day.

No. of gallons per square foot per hour \times 1,045,440
 = No. of gallons per acre per day.

EQUIVALENTS AND CONVERSIONS

In general analytical work the millilitre (ml.) has been substituted for the cubic centimetre (c.c.). Since 1 millilitre equals 1.000027 cubic centimetres, the two terms can, for practical purposes, be regarded as synonymous.

	Gallons.	Litres.	Cubic cms.	Pounds.	Fluid ounces.	Cubic ins.	Cubic feet.
Gallon .	1	4.5459	4545.9	10	160	277.463	0.16
Litre .	0.22	1	1,000	2.2	35.196	61.024	0.0353
Cubic cm.	0.00022	0.001	1	0.0022	0.0352	0.0610	0.000035
Pound .	0.1	0.454	454.6	1	16	27.746	0.016
Fl. ounce	0.00625	0.0284	28.412	0.0625	1	1.728	0.001
Cub. inch	0.0036	0.0164	16.387	0.036	0.5766	1	0.00057
Cub. foot	6.228	28.317	28,317	62.3	1,000	1,728	1

1 cubic metre (kilolitre) = 35.3 cubic feet = 220 gallons.
 1 pint = 20 fluid ounces = 0.568 litre.
 1 litre = 1.759 pints = 35.2 fluid ounces.
 1 pound = 7,000 grains = 453.59 grammes.
 1 cwt. = 112 lbs.
 1 ton = 2,240 lbs.

APPENDIX

437.5 grains	= 1 ounce.
7,000 grains	= 1 pound.
60 minims	= 1 fluid drachm.
8 fluid drachms	= 1 fluid ounce.
20 fluid ounces	= 1 pint.
1 fluid ounce weighs 1 ounce (avoir.).	
8 pints	= 1 gallon.
1 inch	= 2.54 centimetres.
1 yard	= 0.9144 metre.
1 fathom	= 2 yards.
1 centimetre	= 0.3937 inch.
1 metre	= 39.37 inches = 1.0936 yards.
1 mile	= 1,760 yards = 1.61 kilometres.
1 acre	= 4,840 square yards.
1 square mile	= 640 acres.
μ (micron)	= 1/1000th of a millimetre.

Superficial Area

Square or rectangle	= length \times breadth.
Circle	= π (3.1416) \times radius squared.

Volume or Cubic Capacity

Cube or rectangle	= length \times breadth \times height.
Cylinder	= area of base (circle) \times height.
Cone	= area of base \times perpendicular height \div 3
Sphere	= cube of diameter \times 0.5236.

To Convert :—

Grammes into grains multiply by 15.432.

Grains into grammes multiply by 0.0648.

Parts per 100,000 into grains per gallon, multiply by 7 and divide by 10.

Grains per gallon into parts per 100,000, multiply by 10 and divide by 7.

U.S. gallon = 231 cubic inches = 3.7854 litres.

= 0.833 British gallon.

British gallon = 1.2 U.S. gallon.

	Grains per U.S. gallon.	Grains per British gallon.	Parts per 100,000.	Parts per Million.
1 grain per U.S. gallon . . .	1.000	1.20	1.71	17.1
1 grain per British gallon . . .	0.830	1.00	1.43	14.3
1 part per 100,000	0.580	0.70	1.00	10.0
1 part per million	0.056	0.07	0.10	1.0

Hardness Conversion Table

Hardness.	Parts per million.	Grains per gallon.	Parts per 100,000.	German Degrees.
Parts per million, as CaCO_3	1.0	0.07	0.10	0.056
Grains per gallon (Degrees Clark) as CaCO_3	14.3	1.00	1.43	0.80
Parts per 100,000, as CaCO_3	10.0	0.70	1.00	0.56
German degrees = parts per 100,000 as CaO	17.8	1.24	1.78	1.00

TEMPERATURE

$$\frac{F - 32}{9} = \frac{C}{5} \quad \begin{array}{l} F = \text{Fahrenheit.} \\ C = \text{Centigrade.} \end{array}$$

Therefore :—

To convert degrees Centigrade into degrees Fahrenheit multiply by 9, divide by 5, and add 32.

To convert degrees Fahrenheit into degrees Centigrade subtract 32, multiply by 5 and divide by 9.

Absolute zero : — 273° C.

Atmospheric Pressure and Boiling-point of Water

Number of atmospheres.	Boiling-point.
1	100° C., 212° F.
1½	112·2° C., 234° F.
2	120·6° C., 249° F.
3	134° C., 273° F.
4	144° C., 291° F.

Head of Water and Pressure

1 foot head of water = 0·4331 pounds per square inch pressure.

1 pound per square inch pressure = 2·31 feet head of water.

RAINFALL

- A rain day* = 0·01 inch of rain or more.
(Over 0·005 inch is recorded as 0·01 inch. Under 0·005 inch is ignored.)
- A wet day* = 0·04 inch of rain or more.
- A wet spell* = 15 or more consecutive wet days.
- A dry spell* = 15 or more consecutive days with less than 0·04 inch of rain on any one day.
- A partial drought* = 29 or more consecutive days, the mean rainfall of which does not exceed 0·01 inch per day.
- An absolute drought* = 15 or more consecutive days, no one of which is a rain day.
- Average annual rainfall for British Isles* (Standard period, 1881–1915) . . . 41·41 inches.
- “ “ “ “ “ “ (1870–1936) . . . 42·64 “
- “ “ “ “ “ “ *London* . . . 25 “
- 1 inch of rainfall = 4½ gallons per square yard or 22,624 gallons (101 tons approx.) per acre.

GASES USED IN WATER TREATMENT

Dangers and Precautions

Chlorination. The gases normally used in large-scale chlorination of water are chlorine and ammonia. Sulphur dioxide is sometimes used for dechlorination purposes. These gases are contained in liquid form in pressure cylinders, the usual capacities of which are :—

Chlorine : 10, 70 and 150 lbs. Cylinders painted yellow.

Ammonia : 32, 54, 65 and 108 lbs. Cylinders painted black and red.

Sulphur dioxide : 56 and 112 lbs. Cylinders painted green.

Chlorine is also supplied in drums of 10 cwt. and 16 cwt. and tank wagons of 10-ton capacities.

The use of these gases is potentially dangerous, but the risks can be minimised and reduced to negligible proportions by suitable precautions. These precautions include :—

(a) Instruction of the waterworks staff in the properties and dangers of the materials.

(b) Careful handling of cylinders in transit, storage, situation and operation.

(c) Proper operation and regular supervision of all parts of the chlorination equipment, including cylinders, pipe-lines, absorption towers, panels, etc.

(d) Provision of emergency gas masks and first-aid materials, with instruction in first-aid.

Properties of the Gases. See Chapter XLI.

At 80° F. the pressure per square inch in a chlorine cylinder is approximately 100 lbs., and in an ammonia cylinder 140 lbs. These pressures are increased by heat and reduced by cold. Thus, at 100° F. they are approximately 140 and 200 lbs. per square inch respectively. The fusible plugs on cylinders melt at approximately 160° F. (Gerstein, 1937).

One part of liquid chlorine produces 490 parts of gaseous chlorine, and one part of liquid ammonia becomes 823 parts of gaseous ammonia.

Both chlorine and ammonia are poisonous gases, and in the presence of moisture are highly corrosive.

In contact with the skin, liquefied gases, particularly ammonia, cause burns similar to thermal burns.

The gases are strongly irritant to eyes, mucous membranes, respiratory tract, lungs, etc.

In parts by volume, 1 part of chlorine gas in 10,000 parts of air is intolerable, and causes severe symptoms after the shortest exposure. Exposure for a few seconds to an atmosphere containing 1 part of chlorine or 5 parts of ammonia in 1,000 parts of air will prove fatal. Exposure to much lower concentrations, such as 1 part in 100,000, will cause injury.

The distinctive odours of chlorine and ammonia reveal their presence in the atmosphere in minute and relatively harmless concentrations, and preventive measures, such as repair of leaks, should then be immediately taken. The odours of chlorine and ammonia can be detected when the concentrations in the atmosphere are approximately 1 and 50 parts per million respectively.

Precautions. In works where chlorine cylinders (and other gas cylinders) are handled, the following forms and leaflets, published by H.M. Stationery Office, should be obtained, and the recommendations made therein closely followed.

Form 1868, Home Office, "Memorandum on Precautions in the Handling, Storage and Use of Liquid Chlorine."

Form 395, Home Office, "Dangers from Gassing and Burns."

Leaflet No. 10, Department of Scientific and Industrial Research, "Methods for the Detection of Toxic Gases in Industry (Chlorine)."

Leaflet No. 3, Department of Scientific and Industrial Research, "Methods for the Detection of Toxic Gases in Industry (Sulphur Dioxide)."

The most important precautions to be observed are:—

1. Those who handle chlorine should be reliable, instructed and trained workers.

2. Cylinders must not be dropped or receive other mechanical shocks. They should be provided with protective caps over the valves, which caps should be kept on when the cylinders are not in use or are empty. Valves should be closed when cylinders are not delivering chlorine.

3. Force, oil or grease should not be applied to valves which cannot be opened. The cylinder should be returned to the suppliers.

4. Cylinders in use should be kept in the vertical position and fixed so that they cannot fall over.

5. Cylinders should be kept under cover, in the dry, at moderate temperature, and away from any inflammable materials. Exposure to bright sunshine, heat from fires, radiators, etc., must be avoided. Temperatures of 110° F. and above are dangerous.

6. Chlorine and ammonia cylinders should preferably be kept in separate rooms.

7. Cylinders and other parts of chlorinating equipment should be installed in rooms or compartments which are separate from the main premises and have separate entrances, away from the entrance to the main building.

8. Ventilation of the chlorine and ammonia plant rooms should be provided at both the roof and floor levels. Chlorine is heavier than air and tends to collect at the lower part. Ammonia is lighter than air and tends to collect in the upper layers of the atmosphere. Where circumstances indicate and permit, pressure fans and suction fans for the inlet and outlet of air respectively can be installed.

9. All equipment should be regularly inspected, kept in good condition and any leaks or defects immediately remedied.

10. A water supply and fire hose should be available. In the event of fire, cylinders should be kept cool by water and removed. Ammonia is very soluble in water, and a contaminated atmosphere can be improved by spraying with water.

11. Suitable gas masks and protective clothing should be kept in accessible positions away from the gas equipment, and maintained in efficient condition. They must be worn in the event of accident and entry to contaminated atmospheres. Masks which have been used in contaminated atmospheres should be reconditioned by the makers. When ordering masks the gases against which protection is required must be specified.

First-Aid. Form 395, Home Office, should be displayed in a prominent position. All personnel should be familiar with its provisions, and the necessary first-aid equipment should be readily available.

Chlorine. Should an accident occur, remove the patient into a pure, warm atmosphere, send for a doctor immediately and apply the following measures pending his arrival.

1. Keep the patient recumbent, relaxed, reassured, quiet and warm; loosen clothing of neck and waist and remove contaminated clothing. Use blankets and hot-water bottles as required and avoid draughts.

2. Give the patient hot drinks of milk, cream or sweetened tea or coffee to which a lump of butter has been added. One or two teaspoonfuls of glycerine in a tumblerful of soda water can also be given. Do not give alcoholic drinks.

3. Encourage the patient to restrain from coughing. *In mild cases*, relief from coughing can be obtained by giving the patient a teaspoonful of Linctus Diamorphine Camphoratus (B.P.C.) or by inhalation of the steamy atmosphere from a vessel containing two teaspoonfuls of friar's balsam in a quart of hot water.

4. In severe cases where the patient's face is bluish or congested, oxygen, or oxygen diluted with $7\frac{1}{2}$ per cent. carbon dioxide, should be administered with a "Novox" or similar apparatus.

5. If the patient is unconscious, breathing is weak or has ceased, apply artificial respiration by Schafer's method, combined with administration of oxygen, or oxygen diluted with $7\frac{1}{2}$ per cent. of carbon dioxide. Continue artificial respiration for several hours if necessary.

Ammonia. The first-aid treatment for ammonia gassing is, in general, similar to that recommended for chlorine gassing. If the patient is conscious, the drinking of large volumes of water should be encouraged. Mouth burns can be treated by gargling with a 2 per cent. boric acid solution. For eye burns, wash freely with water and 2 per cent. boric acid solution.

All clothing contaminated with ammonia should be removed, the skin washed freely with clean, cold water, and skin burns covered with a "burn dressing" from the first-aid box.

Sulphur Dioxide. This gas is less hazardous to handle than chlorine, but exposure of even very short duration to atmospheres containing 1 part of sulphur dioxide in 1,000 parts of air is dangerous. Much lower concentrations, such as 1 part in 100,000 parts of air, are injurious and must be prevented.

Cylinders and other parts of the equipment should, therefore, be handled with the same care as in the case of chlorine, and any leaks or defects immediately repaired.

In the event of an accident, a doctor should be sent for and first-aid applied to the patient as for chlorine gassing. If breathing is weak, or has stopped, artificial respiration with administration of oxygen should be started at once and, if necessary, continued for hours.

It is emphasised that prevention is better than cure, and dangers can be avoided by proper handling, design, operation and supervision of chlorinating equipment.

Carbon Dioxide and Carbon Monoxide. Carbon dioxide is used at some waterworks where softening by the lime process takes place. It is usually produced by the combustion of coke, and the gas may be contaminated with carbon monoxide which is highly poisonous. Carbon dioxide (CO_2) and carbon monoxide (CO) may also accumulate in the atmospheres of tunnels, wells and headings and at lime kilns.

For the methods of detection, etc., see Leaflet No. 7, Department of Scientific and Industrial Research, "Methods for the Detection of Toxic Gases in Industry (Carbon Monoxide)."

Carbon monoxide is colourless and odourless and it is, therefore, most insidious in its action. Whenever there is a risk of its presence in any confined space, men should not enter until tests to ensure safety have been carried out.

See Home Office Form 395 for first-aid treatment for carbon monoxide gassing.

Send for a doctor and apply first-aid immediately. The patient must be removed into the fresh air and kept warm, recumbent and at

rest. If breathing is shallow, or has stopped, apply artificial respiration and continue for hours, if necessary. Oxygen should also be administered, with carbon dioxide if available, as in cases of chlorine gassing. After regaining consciousness, the patient must be carefully watched and attended until fully restored.

References

- GERSTEIN. 1937. *Jour. Amer. Wat. Wks. Assoc.*, 29, 2.
See also *Jour. Amer. Wat. Wks. Assoc.*, 27, 9 (1935) and 28, 11 (1936).

Small-Scale and Emergency Chlorination

Materials Available

(a) Sodium hypochlorite solutions, such as "Chloros," "Hychlor," "Conchlor," "Voxsan," etc., have available chlorine contents of 10 per cent. to 15 per cent. Electrolytic sodium hypochlorite solutions, e.g., "Milton," have available chlorine contents of approximately 1 per cent.

(b) Bleaching powder (chloride of lime) has available chlorine content of 33 per cent. to 35 per cent.

One gallon of sodium hypochlorite solution (10 per cent.) or 3 lbs. of bleaching powder are each equivalent to 1 lb. of chlorine.

1 lb. of chlorine added to 100,000 gallons of water (1 gallon = 10 lbs.) = 1 part per million of chlorine.

Approximate Amounts of Sodium Hypochlorite Solution (10 per cent.) and Bleaching Powder (33½ per cent.) required, per 1,000 gallons of water, to give various doses of chlorine

Chlorine dose. In parts per million.	Sodium hypochlorite solution (10 per cent.).		Bleaching powder (33½ per cent.).	
	Fluid ozs.	C.c. or ml.	Ozs.	Grammes.
1	1½	45	½	14
10	16	454	5	142
20	32	909	10	284
50	80	2,272	25	710

Crude or Domestic Measures

Sodium hypochlorite solution :—

- 1 teaspoonful = ⅙ fluid ounce.
1 dessertspoonful = ⅓ fluid ounce.
1 tablespoonful = ½ fluid ounce.
1 tumblerful = 10 fluid ounces.

Bleaching powder :—

- 1 level teaspoonful = ⅓ ounce.
1 level dessertspoonful = ⅔ ounce.
1 level tablespoonful = 1½ ounce.

To ascertain the capacities of tanks, see formulæ on p. 806.

Short formulæ to ascertain approximate capacities :—

(a) of a water main or pipe :—

$$d^2 \div 30 = \text{gallons per 1 foot of main. } d = \text{diameter in inches.}$$

(b) of a cylindrical tank or well :—

$$r^2 \times 20 = \text{gallons per 1 foot depth of tank. } r = \text{radius in feet.}$$

MINISTRY OF HEALTH CIRCULAR 1684 * (1938)

Water Supplies

THE Minister of Health feels it incumbent upon him, in the light of recent experience, to remind water undertakers of the serious responsibility which rests upon them in relation to the purity of the public water supplies which they control.

It is the statutory duty of all Local Authorities operating under the Public Health Acts to ensure that water supplied by them to consumers is at all times wholesome, and a like responsibility is expressly placed by Parliament upon water undertakers, whether Local Authorities or Statutory Companies, who derive their powers from special statutory enactments.

The relative immunity from serious outbreaks of water-borne disease that the country has long enjoyed must not be allowed to obscure the paramount importance of taking all possible steps to ensure that this responsibility is adequately discharged and every practicable precaution adopted to safeguard the purity of supplies. The machinery and methods of control, which must necessarily vary with the circumstances of different undertakings, are matters for the decision of the responsible authorities themselves, but it will be realised that the first necessity is that the undertaking should be under the supervision of a qualified engineer who, in the case of the larger undertakings owned by Local Authorities, should be a chief officer of the Authority directly responsible to the appropriate Committee, and in all cases should be in a position to give detailed personal attention to the work. The Minister has no doubt that water undertakers generally will appreciate the need for maintaining the high standards of administration which are rightly demanded in a matter of such fundamental importance to public health, but the results that may ensue from neglect of precautionary measures are so serious that the Minister regards it as his duty, at the present time, to impress upon all water undertakers the imperative need for unremitting care in the supervision of the water supplies for which they are responsible. *

Where water is being supplied without treatment, the water undertakers must satisfy themselves that this practice can safely be continued. For this purpose, they should keep a constant watch on the quality of the water by frequent analyses. How often the analyses should be made in a particular case depends on local conditions, *e.g.*, on the character of the source and of its gathering ground and their position in relation to each other. The Minister is satisfied that under modern conditions more frequent analyses are needed in many cases as a minimum precautionary measure, particularly where there is a tendency to fluctuation in the composition or bacterial content of the water. The water undertakers should be guided as to the frequency of

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analyses by the views of their expert advisers after examination of the local conditions. It is not sufficient, however, to rely on results from analyses alone. Regular and frequent inspections should be made of the area forming the gathering ground of any spring or stream used as a source of supply and of areas surrounding underground sources of supply situate in or near the outcrop of the strata from which the water is drawn, and all practicable steps should be taken to remove possible sources of contamination in these areas. If, as a result of their analyses and inspections or for any other reason, the water undertakers have cause to think that any of their sources of water supply cannot be made and kept free from liability to pollution, they should immediately treat the water by effective methods of purification.

In a separate communication to the water undertakers concerned, particular attention is being drawn to the need for special safeguards where water is supplied from wells or borings into the chalk or limestone at or near the outcrop of those formations.

Where the water is treated, the treatment should as far as possible be automatically controlled, and where the treatment includes chlorination, the dosage should be automatically and continuously recorded. The efficacy of any form of treatment given should be verified by frequent tests of the treated water. The method, extent and control of treatment required in any particular case are also matters on which the water undertakers should be guided by expert advice. Periodic analyses should be made of the raw water in order to keep a check on any change in its character and on the treatment needed. The Minister would, however, stress the point that treatment of the water should be regarded, not as a complete security in itself, but as complementary to the taking of all practicable steps to seek for and remove the causes of pollution of the raw water.

The utmost vigilance is also required to ensure that no risk of contamination of the water supplies arises from operations in connection with the normal maintenance and improvement of waterworks, such as extensions of the works, the reconditioning of wells, reservoirs, and filters, the repair of pumping plant, etc.; and in some cases, *e.g.*, where men are engaged on work in a well, it is essential either to cut off the supply from the well until the work is completed or to give precautionary treatment to the water.

The Minister would emphasise that the administrative responsibility for a service of such vital importance to health can only be successfully discharged if there is effective collaboration and co-operation between those responsible in their various capacities for the conduct and efficiency of the undertaking and between the water undertakers and the Local Authorities of areas served by them. It is essential that Local Authorities who are themselves water undertakers should ensure that the Water Committee and its officers work in close co-operation with the Public Health Committee and the Medical Officer of Health. Where the water undertakers are not the Local Authority for an area supplied by them, they should always be ready, on request, to furnish full

information to that Local Authority or its Medical Officer of Health as to the quality of the water supplied and the precautions taken to safeguard its wholesomeness. On the other hand, Local Authorities should make it their duty to bring to the notice of water undertakers cases of enteric fever or other diseases likely to be water-borne, and also any building development or other operations in the Local Authority's area which might affect the purity of a source of water supply.

The Minister would be happy at any time to arrange for his officers to discuss with those concerned any points arising out of this letter on which it is thought the Department can be of assistance.

MINISTRY OF HEALTH MEMO. 221 (1939)

MEMORANDUM ON THE SAFEGUARDS TO BE ADOPTED IN DAY TO DAY ADMINISTRATION OF WATER UNDERTAKINGS *

General

1. THE prevention of water-borne diseases was the chief and almost the only concern of sanitation as it was understood a hundred years ago. Recent events have shown that even now it can be achieved only by careful and constant supervision of supplies of drinking water. Between 1911 and 1937 there occurred 21 outbreaks of disease, conveyed by public water supplies, of such gravity as to merit detailed mention in the annual reports of the Medical Officer of the Local Government Board and the Chief Medical Officer of the Ministry of Health. Pollution prior to storage and distribution was responsible for 13 of these outbreaks, four of the 13 involving overground supplies and nine of them underground supplies. Pollution during storage occurred in two cases. Pollution during distribution appears to have occurred in six instances. The numbers of known cases of disease resulting from these outbreaks were: enteric fever (including paratyphoid) 1,237; bacillary dysentery 2,800; and gastro-enteritis 7,439.

2. The Minister has recently † brought to the notice of all water undertakers the need for unremitting care in the supervision of the water supplies for which they are responsible. Particular stress was laid upon the importance of effective collaboration and co-operation between the various officers responsible for the conduct and efficiency of the undertaking and also between the water undertakers and the local authorities of areas served by them. The importance of this aspect of water administration is again emphasised.

3. The object of this memorandum is to draw attention to the precautions which should be taken in the day to day administration of water supplies. These precautions are no more than are already recognised as good practice in water administration and water under-

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† Circular 1684, dated March 12th, 1938.

takers should carefully review their arrangements and take appropriate steps in the light of the circumstances of their undertaking to improve their practice where this is necessary.

4. There are in England and Wales some 530 local authorities and 15 joint bodies supplying water under the Public Health Acts, and 260 local authorities, 33 joint bodies and 173 water companies supplying water under powers given by Special Acts. Three-quarters of the population of the country is supplied with water obtained from over-ground sources—from rivers, streams and springs—and the remaining one-quarter from wells and borings into water-bearing strata. All the bodies referred to are under statutory obligation to provide wholesome water for the use of their consumers. The variety of sources and conditions is such that it is not possible to lay down any one method applicable to every case of ensuring the fulfilment of this obligation. Undertakers must have regard to the circumstances in their own areas, *e.g.*, the nature and situation of the source from which the supply is drawn and the character and formation of the gathering ground, and must themselves decide, on competent advice, the machinery and methods of control which are most suitable to their own local conditions.

Health of Workmen employed on Waterworks

5. Careful discrimination should be exercised in the selection of workmen employed on waterworks other than works where no risk to the purity of the water supply is likely to arise, and the clinical history of each such workman, particularly with reference to enteric infection, should be thoroughly investigated in order to determine his suitability for this kind of employment. Any man attacked by illness associated with looseness of the bowels should be suspended from work until his recovery is complete and medical examination shows that he is safe to return to work. Every new man proposed to be employed on any part of the works where there is risk of his contaminating the water should be examined by means of a Widal test of his blood in order to ascertain whether or not he is likely to be a typhoid carrier. If a positive result is obtained which is not attributable to preventive inoculation, he should not be employed unless bacteriological examination of his excreta on at least three occasions shows negative results as regards the presence of pathogenic bacteria.

In the case of local authorities who are water undertakers, these examinations should be arranged for by their Medical Officer of Health, who will review all the circumstances and whose decision on the question of the employment or continued employment of any man for this kind of work should be final. The Medical Officer of Health or other expert medical adviser should be similarly consulted in the case of other water undertakers.

General Cleanliness of Waterworks

6. All buildings, machinery, apparatus and yards used for waterworks purposes should be kept scrupulously clean. Proper and adequate

sanitary accommodation and washing facilities should be provided at any part of the works where men are regularly employed. All such accommodation should be regularly inspected, and all drains should be periodically tested in order to ensure that no leakage occurs.

Protection of Sources of Supply

7. Whatever the source of supply may be, and whether or not purification treatment is given to the water before it is brought into service, every effort should be made to secure that so far as is practicable the raw water is protected from pollution.

8. **Upland Overground Sources.** Where the source of water supply is a reservoir impounding the head waters of a stream or an intake near the source of the stream, the water undertakers should, wherever reasonably practicable, acquire the whole of the gathering ground above the reservoir dam or the intake, and protect the reservoir or intake by adequate fencing. Steps should be taken to secure that drainage from farmyards or houses remaining on the gathering ground or the manuring of land on the gathering ground does not pollute the source of supply.

9. Where it is not practicable to acquire the gathering ground and thus control it, it should be part of the routine duty of the water undertakers' staff to make regular and frequent inspections of the whole of the gathering ground with a view to detecting possible causes of pollution. Any building development on the gathering ground should be carefully watched for risk of contamination of the source of supply.

10. **Springs.** Where the source of supply is a spring, a sufficient area of land surrounding the spring should be acquired by the water undertakers to enable them to apply adequate protective measures, and a close watch should be maintained by the water undertakers' staff over the area in the vicinity of the spring so that any possible source of pollution may be quickly detected.

11. **River Supplies.** Where a supply is obtained from the lower reaches of a river or stream regular and frequent inspections should be made of the course of the river or stream above the intake with a view to ascertaining the likelihood of pollution being discharged.

12. **Underground Sources.** A well or borehole forming a source of supply should be made watertight to such a depth as will prevent any surface pollution from entering, and there should be an efficient sealing between the casing of the borehole and the surrounding ground. Periodic inspections of wells and boreholes should be made in order to ensure that the lining is sound. The water undertakers should acquire a sufficient area of land surrounding the site of the well or borehole to enable them to protect the immediate surroundings. Where the well or borehole is on or near to the outcrop of the strata from which the water is drawn, it should be the routine duty of the water undertakers' staff to make regular and frequent inspections of the area within at least two miles of the site of the well or boring with a view to detecting possible causes of pollution. Particular attention should be paid to any cesspools and soakaways in such an area and the water under-

takers should satisfy themselves that danger to their source of supply is not likely to arise from them. Further, a map showing details of any sewerage system within this area should be kept.

13. The inspections by the water undertakers' staff referred to in the preceding paragraphs should be carefully recorded and reports made to the water undertakers or their appropriate Committee. Each report should draw special attention to any alterations which have occurred on the gathering ground since the preceding report. Where the reports indicate a possible cause of pollution of the source of supply, the water undertakers should take such action as may be available to them to remove it. It will be appreciated that these reports will assist materially in interpreting the results of periodic analyses of the raw water.

Analyses ²

14. Where water is being supplied without treatment, the water undertakers should make frequent and regular analyses of the water in order to satisfy themselves that this practice may safely be continued. If there is a tendency to fluctuation in the composition or bacterial content of the water, or if inspection of the gathering ground of the source of supply shows possible risk of pollution, analyses should invariably be made at very short intervals. How frequently and at what times the analyses should be made must depend on local conditions and this question should be determined in the case of each water undertaking by the expert views of their advisers after consideration of the local conditions.

15. The results of any analyses must be read in the light of the nature of the source and the condition of the gathering ground, and it is not possible to lay down any hard and fast standard which would be applicable to all supplies. If, however, as a result of analyses and of the inspection of the gathering ground, the water undertakers, acting in the case of local authorities on the advice of their Medical Officer of Health and in other cases on the advice of their experts, have any grounds for suspecting that the water cannot be made and kept free from risk of becoming unwholesome they should not hesitate to subject the water to an effective method of treatment.

16. Where the water is treated it is important that regular analyses should be made of the raw water as well as of the treated water. It will not of course be necessary to make such frequent analyses of the raw water when treatment is given as when it is not, but the analyses should be of sufficient frequency to enable an adequate check to be kept on the character of the raw water as a guide to the treatment required.

Treatment of Water

17. The conversion of a polluted and therefore dangerous water into a safe potable water is a matter requiring the greatest care if the

² For information as to the technique of water analysis, see "Reports on Public Health and Medical Subjects No. 71—the Bacteriological Examination of Water Supplies," obtainable (price 1s. 3d. net) from H.M. Stationery Office.

health of the consumer is not to be jeopardised. There is often a tendency to think that, provided arrangements are made for chlorination, safety is secured whatever the condition of the raw water. It cannot be sufficiently stressed that a policy of reliance on a single line of defence between the consumer and a polluted source of water supply is fraught with danger. Not only should every effort be made, as has been suggested above, to keep the source as free as possible from pollution, but, wherever practicable, the method of treatment should be such as to provide at least two lines of defence, such as, for example, chlorination or other effective form of sterilisation after storage or filtration.

18. Treatment plant should at all times not only be under the supervision of properly trained persons, but should also as far as possible be automatically controlled. Where the treatment includes chlorination, the dosage should be automatically and continuously recorded. The dosage should also be such as to leave residual chlorine after a reasonable period of contact, the period required being determined by the undertakers on expert advice, and frequent tests should be made to ensure this.

Service Reservoirs

19. Service reservoirs from which water passes direct to the consumer should, wherever practicable, be covered. An open reservoir of this kind is dangerous, because any pollution entering it reaches the consumer in a short space of time, and if it is not practicable to cover it, the water should be adequately chlorinated as a safeguard.

Care should be taken to ensure that pollution cannot enter reservoirs through ventilators, manholes, washouts and overflows. Service reservoirs should be periodically inspected with a view to detecting any cracks or other defects which may develop and permit the access of pollution to the water.

Mains and Hydrants

20. All new mains should, after connection with the supply system, but before being used to convey water to consumers, be thoroughly flushed. Where possible chlorinated water should be used for this purpose. Mains that have been cut and repaired should be similarly treated.

The arrangement of air valves and air vents to mains should be such that there is no possibility of pollution entering the mains through them.

21. Ball hydrants form a ready means of ingress of polluting matter into water mains and are therefore a potential source of danger. Water undertakers should take the first opportunity of having them replaced by safer types of hydrant.

Works of Repair and Cleaning

22. It is of the first importance that the arrangements made where works of repair or extension are being carried out are such as to obviate

any risk of danger to the health of the consumer from contamination of the water supply. Instructions to workmen as to their conduct while engaged on such works should be in precise terms, and it should be made clear to them that any breach of the instructions will be followed by dismissal.

23. Where pumps or other machinery have been removed from a well or borehole for cleaning or repair, they should be thoroughly cleansed with chlorinated water before being replaced. New pumps or other machinery should be similarly treated before being inserted in the well or borehole.

24. **Wells and Headings.** Where work is proceeding in a well or heading, the water therefrom should, whenever possible, be cut out of supply and pumped to waste. If this is not possible, the water should be subjected to an effective method of treatment during the period while the work is proceeding and for a period of at least one week after the work has been completed.

25. The workmen should be provided with boots and overalls which should be kept at the waterworks, and the boots should be cleansed with chlorinated water on every occasion before the men enter the well.

26. Sanitary arrangements should be provided at the surface and so designed that any risk of the men's boots being fouled is avoided. Pails, of a type which minimises the risk of splashing or overturning, should be provided for micturition where the men are working. Strict instructions should be given that any man wishing to defæcate must be brought to the surface and that micturition should take place in the pail provided.

27. **Service Reservoirs and Filters.** Precautions similar to those referred to in the preceding paragraph should be taken as regards the provision of sanitary arrangements for men engaged in cleaning reservoirs or filters. The pails for micturition purposes should be placed as near as conveniently possible to the place where the men are actually working. In the case of service reservoirs the precautions set out in paragraph 25 should be observed.

28. Service reservoirs when cleaned should be thoroughly sluiced with clean water, the water being chlorinated wherever practicable.

Maps

29. Each water undertaker should keep an up-to-date record in the form of maps and plans of the sites of their sources of supply and reservoirs and of their distribution system, so that they can ascertain readily how each property in their area is served. A diagram of the pipes and valves in and around engine houses and reservoirs should also be kept.

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